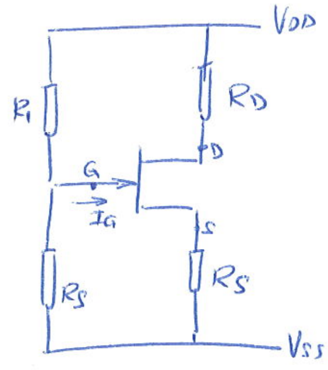
Configuraciones típicas con JFET (i MOS)

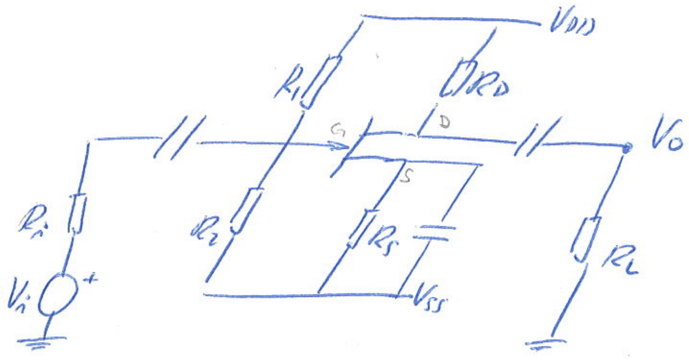
× Circuito general de polarización del JFET:



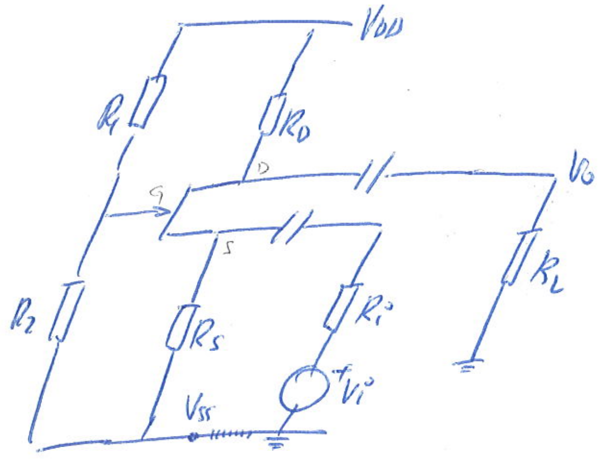
$I_G = 0 \Rightarrow V_G$ se halla directa.

Red de polarización

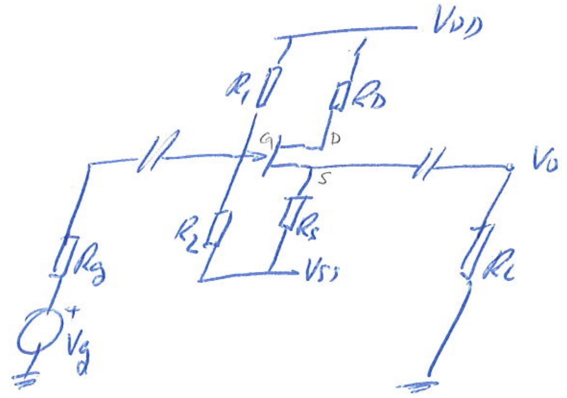
× Surtidor común:



× Puerta común:



× Drenador común



Pequeña señal

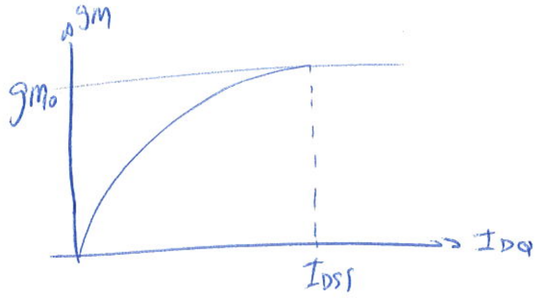
Modelo de parámetros de Admitancias (Y):

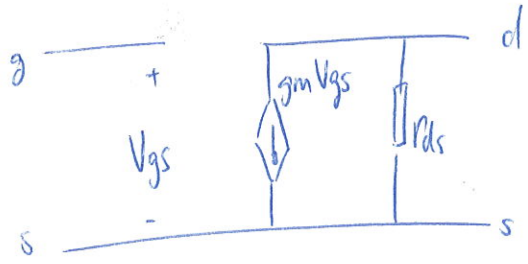
$$Y_{is} = \left.\frac{\partial i_G}{\partial V_{GS}}\right|_Q \qquad Y_{rs} = \left.\frac{\partial i_G}{\partial V_{DS}}\right|_Q \qquad i_g = Y_{is} \cdot V_{gs} + Y_{rs} \cdot V_{ds}$$

$$Y_{FS} = \left.\frac{\partial i_D}{\partial V_{GS}}\right|_Q \qquad Y_{os} = \left.\frac{\partial i_D}{\partial V_{DS}}\right|_Q \qquad i_d = Y_{FS} \cdot V_{gs} + Y_{os} \cdot V_{ds}$$

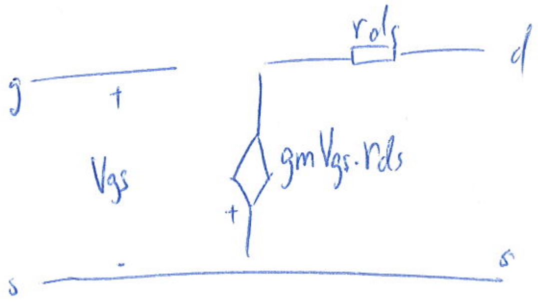
Transconductancia: (conductancia mútua) $g_m = Y_{FS} = \frac{-2 I_{DSS}}{V_p}\left(1 - \frac{V_{GSQ}}{V_p}\right)$; $g_{mo} = \frac{-2 I_{DSS}}{V_p}$

$$g_m = g_{mo}\sqrt{\frac{I_{DQ}}{I_{DSS}}}$$



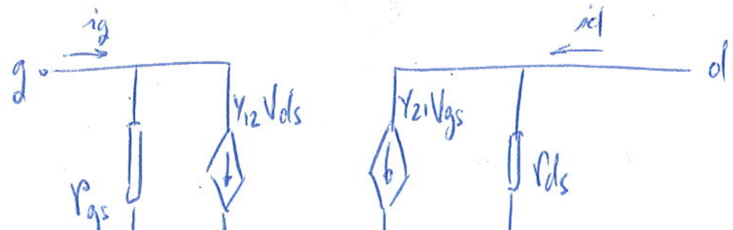


Eq. Th.



modelo: $Y_{rs} \to 0$

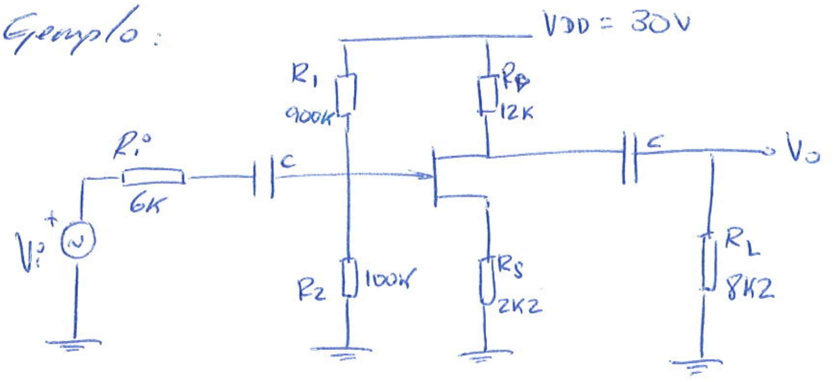
$r_{gs} \to \infty$



$Y_{12} \cdot V_{ds} = Y_{rs} \cdot V_{ds}$ $\qquad$ $Y_{21} \cdot V_{gs} = Y_{FS} \cdot V_{gs} = g_m \cdot V_{gs}$

$r_{gs} = \frac{1}{Y_{11}} = \frac{1}{Y_{is}}$ $\qquad$ $r_{ds} = \frac{1}{Y_{22}} = \frac{1}{Y_{os}}$

+ Ejemplo:



Datos: $I_{DSS} = 3mA$

$V_P = -2'4V$

$r_{ds} \to \infty$

$C\omega \to \infty$

Hallar: 1/ Q?

2/ AV?, Ai?, Zin?, Zo?

$C\omega \to \infty$: $|Z_C| = \frac{1}{C\omega} = 0$

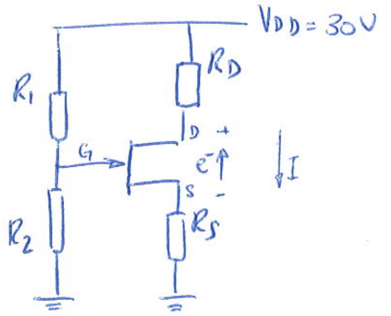
DC	C ≡ C.a.
AC	C ≡ C.c.

Resolución:

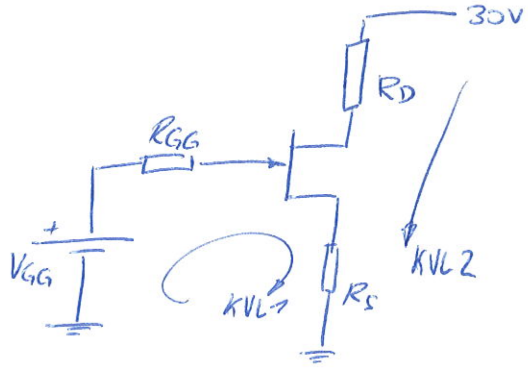
1/ Análisis en DC:

C ≡ —o o—

× Red de polarización:

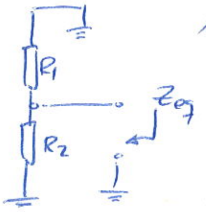


Eq. Thevenin R1 y R2.



$$V_{GG} = \underset{30V}{V_{DD}} \cdot \frac{R_2}{\underset{900K}{R_1} + \underset{100K}{R_2}} = 3V$$

RGG:



$R_{eq} = R_1 // R_2$

$$R_{GG} = 900K // 100K = \frac{900K \cdot 100K}{900K + 100K} = 90K$$

KVL1: (en malla GS) $V_{GSQ} = \underset{3V}{V_{GG}} - I_{DQ} \cdot R_S$

KVL2: (en malla DS) $V_{DD} = I_D R_D + V_{DS} + R_S \cdot \underset{I_D}{I_S} \longrightarrow I_{DQ} = \frac{\overset{V_{DD}}{30V} - V_{DSQ}}{R_D + R_S}$

× Suponiendo SATURACIÓN: $I_{DQ} = I_{DSS}\left(1 - \frac{V_{GSQ}}{V_P}\right)^2$

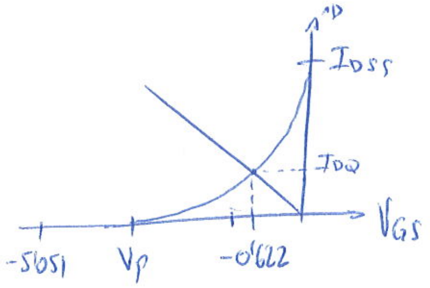
Resolviendo:

$$\left.\begin{aligned} V_{GSQ} &= 3V - I_{DQ}\cdot R_S \\ I_{DQ} &= I_{DSS}\left(1 - \frac{V_{GSQ}}{V_P}\right)^2 \end{aligned}\right\}$$

2 ecuaciones y 2 incógnitas: V_{GSQ}, I_{DQ}

$V_{GSQ} =$ → $-0'622\,V$ / → ~~$-5'051\,V$~~

No es válido pues es $< V_P$:



$V_{GSQ} = 3V - I_{DQ}\cdot R_S$

⇓

$I_{DQ} = \frac{3 - (-0'622)}{2'2K} = 1'65\,mA$ | Verificando $I_{DQ} < I_{DSS}$

$V_{DSQ} = 30 - 1'65\,mA\,(R_D + R_S)$

⇓

$V_{DSQ} = 6'57\,V$ > 0

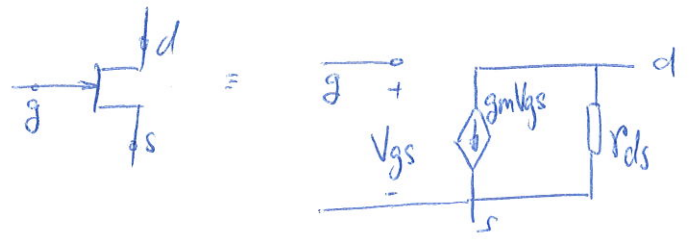
× Verificamos SATURACIÓN: $V_{DSQ} \geq V_{GSQ} - V_P$

$6'57$; $-0'622$; $-2'4V$ → $6'57 \geq -0'622 + 2'4V$ | o.k.

Por tanto estamos en SAT.

2) Análisis en A.C.

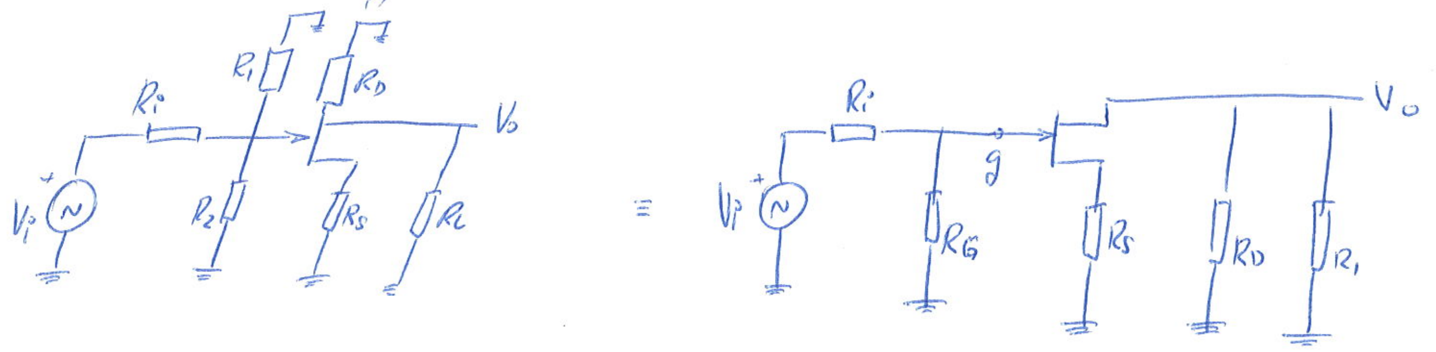
Por estar en SAT →



$r_{ds} \to \infty$

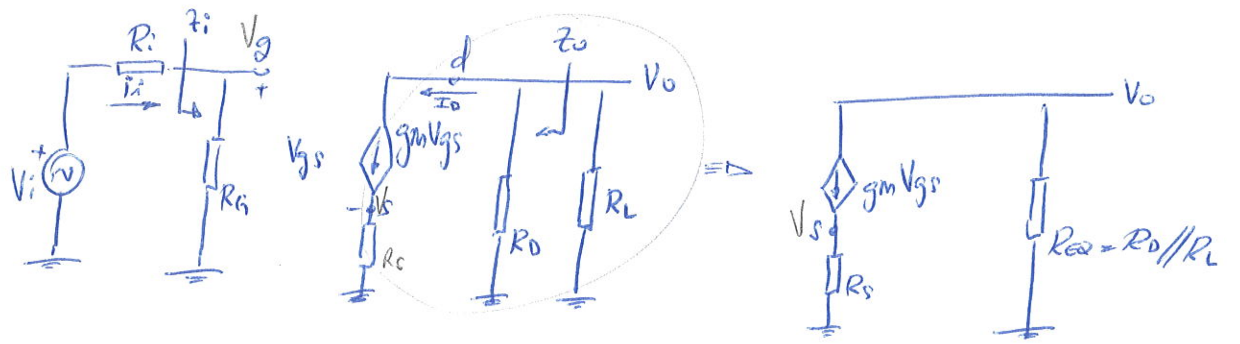
C ≡

El circuito nos queda:



$R_G = R_1 // R_2 = 90K$

Utilizando el modelo:



• Av = ? (Ganancia de tensión)

$$A_v = \frac{v_o}{v_i}$$

Vo? $\quad V_o = -g_m V_{gs} (R_D // R_L)$

Vi? $\quad V_g = V_{gs} + \overbrace{g_m V_{gs} R_s}^{V_s}$; $\quad V_g = V_i \frac{R_G}{R_G + R_i}$ $\quad \Rightarrow \quad V_i = \dfrac{V_{gs}(1 + g_m R_s)}{\frac{R_G}{R_G + R_i}}$

$V_{gs} = V_g - V_s$

de otra manera: $\quad V_{gs} = V_g - V_s = \underbrace{V_i \frac{R_G}{R_G + R_i}}_{V_g} - \underbrace{g_m V_{gs} \cdot R_s}_{V_s = I_D \cdot R_s} \Rightarrow V_i = \dfrac{V_{gs}(1 + g_m R_s)}{\frac{R_G}{R_G + R_i}}$

$$A_v = \frac{V_o}{V_i} = \frac{-g_m V_{gs} (R_D // R_L)}{V_{gs} \cdot \frac{1 + g_m R_s}{\frac{R_G}{R_G + R_i}}} = -\frac{g_m (R_D // R_L)}{1 + g_m R_s} \cdot \frac{R_G}{R_G + R_i} = -1'7$$

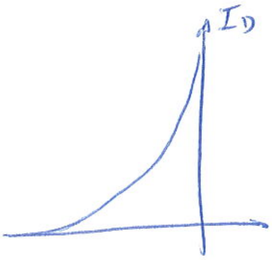
$$g_m = \left. \frac{\partial i_D}{\partial V_{GS}} \right|_Q = -\frac{2 I_{DSS}}{V_P} \left(1 - \frac{V_{GS}}{V_P}\right)^2 = 1'86 \frac{mA}{V} = 1'86 \; m\Omega^{-1}$$

$= mS$ (milisiemens).

Estudio del Resultado:

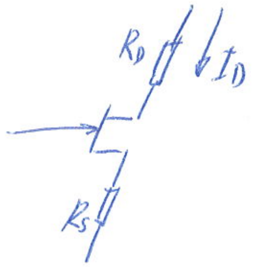
$$A_v = -\frac{g_m (R_D // R_L)}{1 + g_m R_s} \cdot \frac{R_G}{R_G + R_i}$$

Avco. inversión de fase. Invierte la salida	Depende del JFET y la polarización	Depende del generador y del "trozo" de entrada. Es la amplificación. ≥ 1 $R_G \gg R_i$



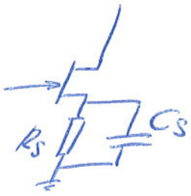
$g_m \uparrow$ = pendiente $\uparrow$

$g_m \uparrow$ si $I_{DQ} \uparrow$



+ Normalmente interesa $Z_i \uparrow\uparrow$ para que $V_{Ri} \downarrow\downarrow$ $\quad V_{R_i} = V_i \dfrac{R_i}{R_i + Z_i}$

+ $A_v \simeq \dfrac{-g_m (R_D // R_L)}{1 + g_m R_S}$. Para $A_v \uparrow \Rightarrow$
- $g_m \uparrow$
- $R_S \downarrow$ = Podemos poner C_S. (no modifica Q)
- $R_L \uparrow$
- $R_D \uparrow$



$\uparrow$

$\dfrac{R_G}{R_G + R_i} \simeq 1$, $R_G \gg R_i$

si $R_D \uparrow\uparrow \Rightarrow I_{DQ} \downarrow \Rightarrow g_m \downarrow \Rightarrow A_v \downarrow$

R_D no se puede aumentar en exceso pues $I_{DQ} \downarrow$ y no interesa ya que queremos $A_v \uparrow$.

× $A_i = ?$ (Ganancia de Corriente)

$A_i = \dfrac{i_L}{i_i}$

$\left.\begin{array}{l} i_L = \dfrac{V_o}{R_L} \\ i_i = \dfrac{V_i}{R_G + R_i} \end{array}\right\} A_i = \dfrac{i_L}{i_i} = \dfrac{V_o}{V_i} \cdot \dfrac{R_i + R_G}{R_L} = -20$

$\dfrac{V_o}{V_i} = A_v = -1'7$

× $Z_{in} = ?$ (Impedancia de entrada)

$Z_{in} = R_G = 90 K\Omega$ (por inspección)

$\Downarrow$

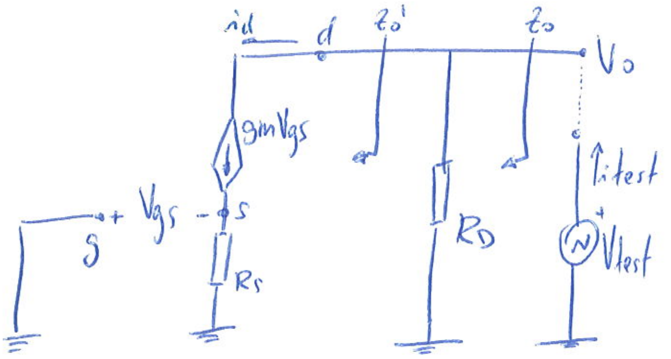
para $Z_{in} \uparrow$ interesa $R_1 \uparrow$, $R_2 \uparrow$ siempre que entre I_G suficiente.

× $Z_o = ?$ (Impedancia de Salida)

Desactivamos fuentes independientes: anulamos V_i por tanto $V_g = 0$.

sabiamos que $V_g = V_i \dfrac{R_G}{R_G + R_i}$

Y el circuito se reduce a:



$V_g = 0 \rightarrow V_{gs} = 0 - V_s = -V_s$ ($0 \equiv V_g$)

$Z_o = Z_o' // R_D$

Se tiene que cumplir:

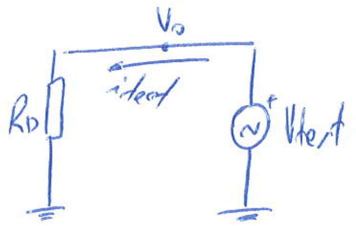
$V_g = 0 \rightarrow V_s = g_m V_{gs} R_s \Rightarrow V_{gs} = 0 - V_s = -g_m V_{gs} R_s \rightarrow V_{gs}(1 - g_m R_s) = 0 \Leftrightarrow V_{gs} = 0 \Leftrightarrow V_s = 0 \Leftrightarrow i_d = 0 \Leftrightarrow Z_o' = \infty$

$V_{gs} = -V_s \qquad I_D = g_m V_{gs}$

$Z_o = Z_o' // R_D = R_D$ (con $Z_o' = \infty$)

De otra forma:

$$Z_o = \frac{V_{test}}{i_{test}} = \frac{V_{test}}{\frac{V_{test}}{R_D}} = R_D$$

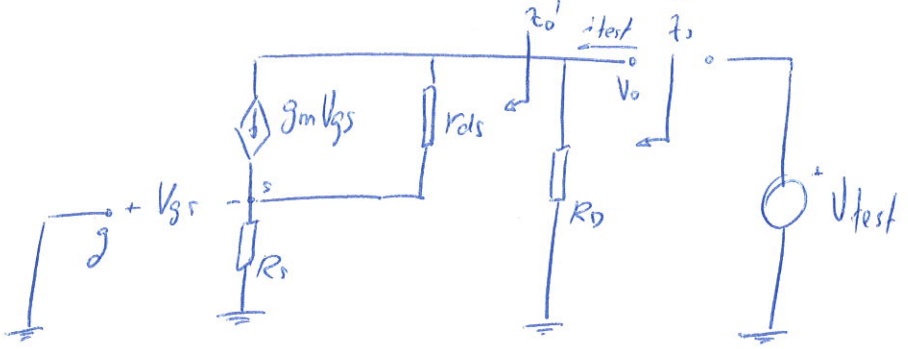


$$i_{test} = \frac{V_{test} - 0}{R_D}$$

En pequeña señal: $i_d = 0$ si $i_D = cte = I_{DQ}$

plana pues $r_{ds} = \infty$ (pendiente) y por tanto i_D no varía.

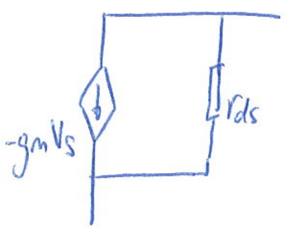
Si $r_{ds} \neq \infty$ (practica 5)



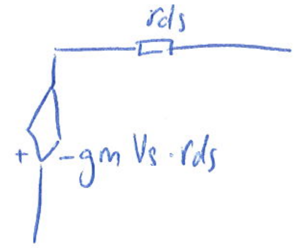
$Z_o = Z_o' // R_D$

$V_{gs} = V_g - V_s = -V_s \qquad V_s \neq 0$

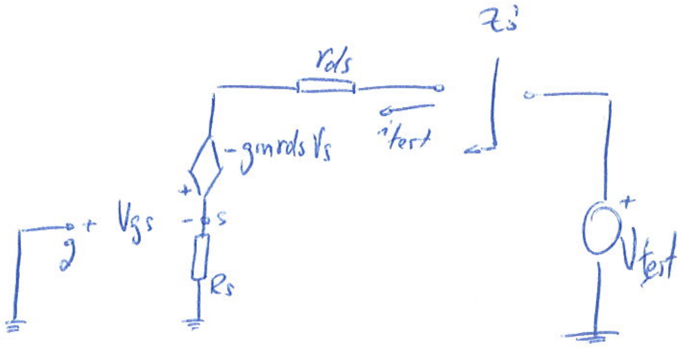
($V_g = 0$)



≡ Eq. Th.



→



$Z_o = Z_o' // R_D$

$$Z_o' = \frac{V_{test}}{i_d}$$

$$V_{test} = i_{test} \cdot r_{ds} - (-g_m r_{ds} V_s) + i_{test} \cdot R_S = i_{test} (r_{ds} + R_S) + g_m r_{ds} V_s$$

$$i_d = i_{test} = \frac{V_{test}}{r_{ds} + R_S + g_m r_{ds} R_S} \quad \longleftarrow \quad i_{test}(r_{ds} + R_S) = V_{test} - i_{test} R_S g_m r_{ds}$$

($V_s = i_{test} \cdot R_S$)

$$Z_o' = r_{ds} + R_S + R_S g_m r_{ds}$$

$$Z_o = Z_o' // R_D = (r_{ds} + R_S + R_S \cdot g_m \cdot r_{ds}) // R_D \simeq R_D$$

Aprox. si $r_{ds} \gg \frac{1}{g_m}$ si $R_S \sim R_D$ (del orden de)

$R_S \gg R_D$

$r_{ds} g_m \gg 1$

$r_{ds} \gg R_D$

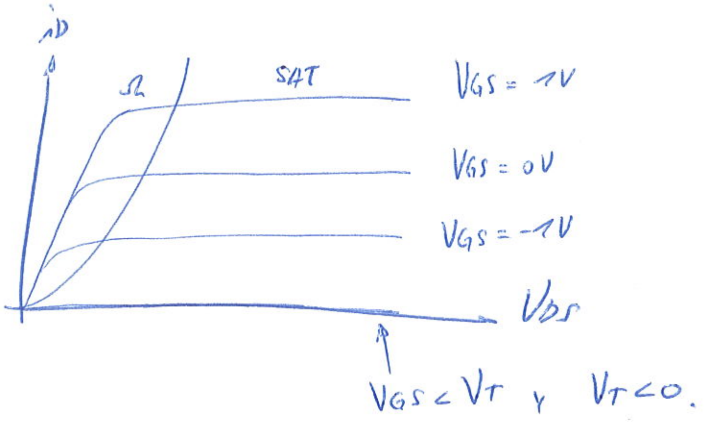
MOS

$V_T \equiv$ tensión de umbral ($\equiv$ Threshold Voltage)

- NMOS vaciamiento: $V_T < 0$

$V_{GS} = 0 \rightarrow$ conduce ($V_G \downarrow\downarrow$)

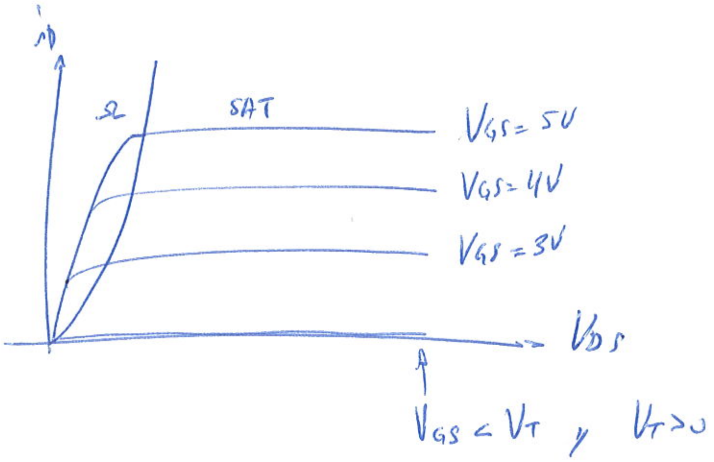
$V_{GS} < V_T \Rightarrow i_D = 0$



- NMOS acumulación: $V_T > 0$

Conduce para $V_{GS} > V_T$ ($V_G \uparrow\uparrow$)

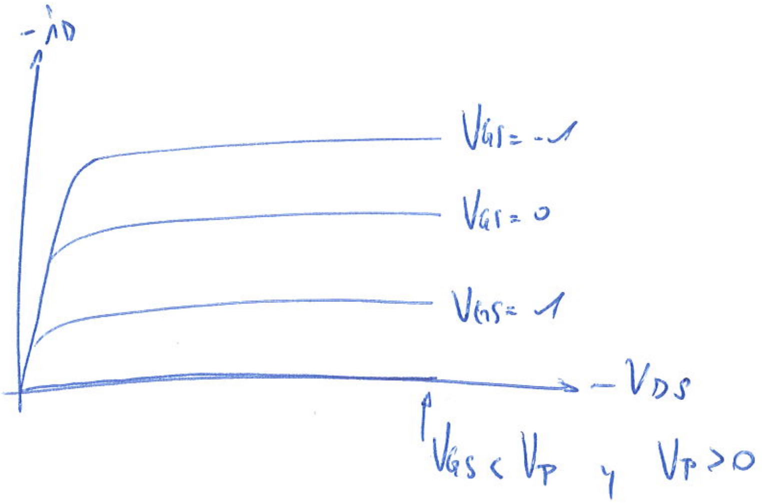
$V_{GS} < V_T \Rightarrow i_D = 0$



- PMOS vaciamiento: $V_T > 0$

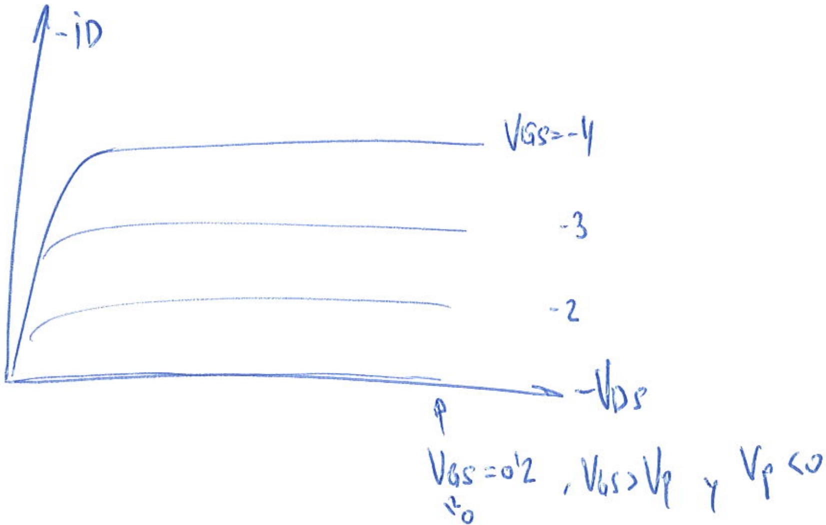
En corte si $V_{GS} < V_P \Rightarrow i_D = 0$

* tensiones y corrientes negativas para que la corriente circule del Drenador al Surtidor.

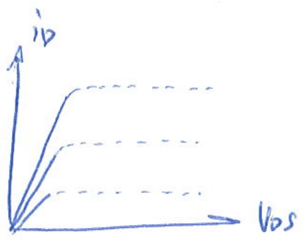


- PMOS acumulación: $V_T < 0$

Conduce para $V_{GS} < V_P$



ZONA OHMICA



$V_{GD} \simeq V_{GS} \rightarrow V_{GD} = V_{GS} + V_{SD} = V_{GS} - V_{DS} \simeq V_{GS}$

$|V_{DS}|$ pequeña.

Resistencia del canal: $I_D = \frac{V_{DS}}{R_{canal}}$.

SATURACIÓN

$|V_{DS}| \uparrow \Rightarrow |V_{GD}| \downarrow$

NMOS: $\boxed{V_{DS} \geq V_{GS} - V_p}$

Válida para NMOS Acumulación $V_p > 0$
" Vaciamiento $V_p < 0$.

PMOS: $\boxed{V_{DS} \leq V_{GS} - V_p}$

Corriente de Saturación:

$$\boxed{I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2}$$

→ Es válida si $\begin{cases} V_{DS} \geq V_{GS} - V_p & \text{NMOS} \\ V_{DS} \leq V_{GS} - V_p & \text{PMOS} \end{cases}$

No hay corte → $\begin{cases} V_{GS} > V_p & \text{NMOS} \\ V_{GS} < V_p & \text{PMOS}. \end{cases}$

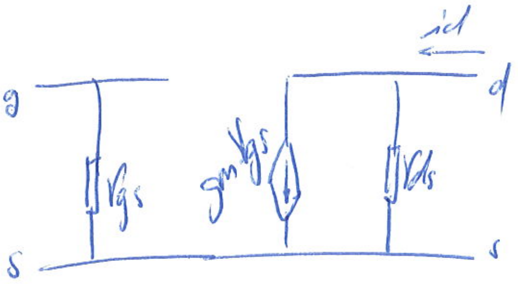
Expresiones alternativas para Corriente de Drenador:

NMOS

- I_D en Ω; $I_D = \mu_n \cdot C_o \cdot \frac{W}{L}\left[(V_{GS} - V_p)V_{DS} - \frac{V_{DS}^2}{2}\right]$
  $V_{DS} \leq V_{GS} - V_p$
- I_D en SAT; $I_D = \frac{\mu_n \cdot C_{ox}}{2} \cdot \frac{W}{L}(V_{GS} - V_p)^2$
  $V_{DS} \geq V_{GS} - V_p$

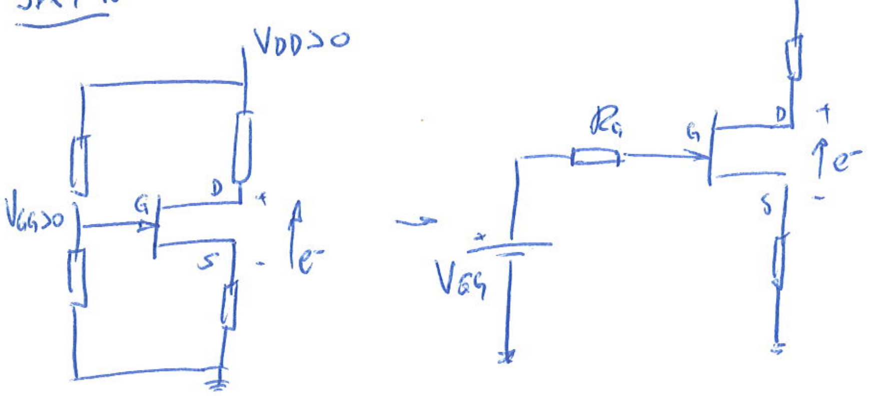
$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$

Modelo en Pequeña Señal (MOS) . Coincide con el JFET.



$$g_m = \left.\frac{\partial i_D}{\partial V_{GS}}\right|_Q = \frac{-2 I_{DSS}}{V_p}\left(1 - \frac{V_{GSQ}}{V_p}\right)$$

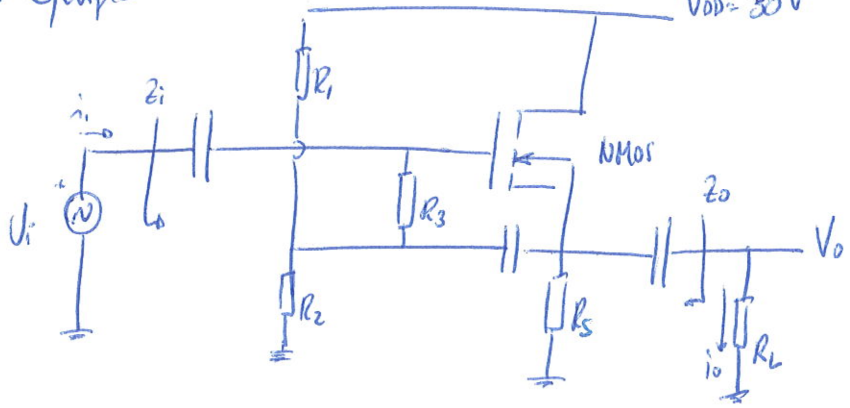
JFET N



Tipo N: los e- se mueven del Surtidor al Drenador, esto crea un potencial V_D positivo, por tanto V_{DD} también lo es y entonces V_{GG} será positivo.

V_D tiene que ser mayor que V_S (Movimiento de e- del - al +.

→ Ejemplo



Datos

Mos | $|I_{DSS}| = 4\,mA$ | $|V_p| = 4\,V$ | $r_{ds} = 40\,K$

$R_1 = 22\,K$
$R_2 = 68\,K$
$R_3 = 2\,M$
$R_S = 18\,K$
$R_L = 82\,K$

$g_m = ?$

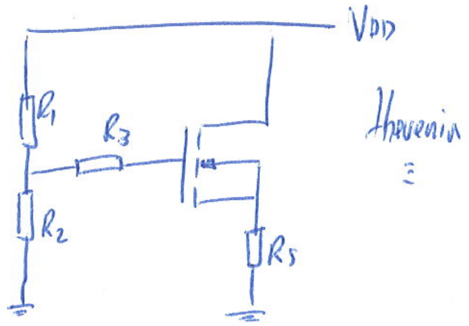
a/ Q?   b/ A_v, A_i, Z_i, Z_o.

Por ser un NMos se debe cumplir $I_D > 0 \Rightarrow \underline{I_{DSS} = +4\,mA.}$

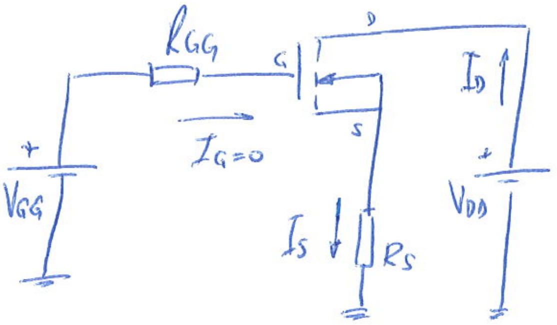
Sabemos que el mos es de acumulación si $V_{GS} = 0$ no conduce.

NMos conduce si $V_{GS} > V_p$ por lo que $V_p > 0$ tenemos que $\underline{V_p = +4\,V.}$

a/ Q? Punto de trabajo.



Thevenin ≡



$$V_{GG} = V_{DD} \cdot \frac{R_2}{R_1 + R_2} = 22'67\,V$$

$$R_{GG} = R_1 // R_2 + R_3 \simeq R_3 = 2\,M$$

$$R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2} << R_3$$

$$V_{GG} = V_{GS} + I_D \cdot R_S$$

KVL_{G-S} : $V_{GS} = V_{GG} - I_S \cdot R_S$ ($I_S = I_D$) $\longrightarrow I_D = \dfrac{V_{GG} - V_{GS}}{R_S}$

KVL_{D-S} : $V_{DD} = V_{DSQ} + I_S \cdot R_S$ ($I_S = I_D$)

suponiendo SAT: $I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_p}\right)^2 = \dfrac{V_{GG} - V_{GS}}{R_S}$

Despejamos V_{GS} : $V_{GS} = V_{GSQ}$ → $5'93\,V$
→ $1'85\,V$ ⇒ se descarta por ser menor a $4\,V$. $V_{GS} > V_p$

$$I_{DQ} = I_D = \frac{\overset{22'67V}{V_{GG}'''} - \overset{5'93V}{V_{GSQ}'''}}{\underset{18K}{R_S}} = 0'93\ mA \quad \rightarrow \text{puede ocurrir } I_{DQ} > I_{DSS}$$

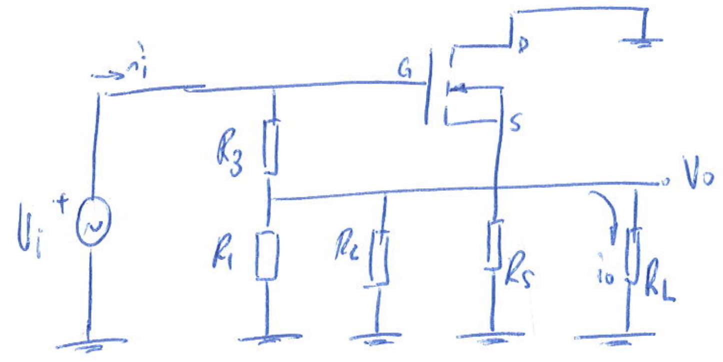
$$V_{DSQ} = \underset{30V}{V_{DD}} - I_{DQ} \cdot R_S = 13'26\ V$$

Comprobamos SAT: $V_{DSQ} \geq V_{GSQ} - V_P$

$13'26 \geq 5'93 - 4 \Rightarrow$ SAT

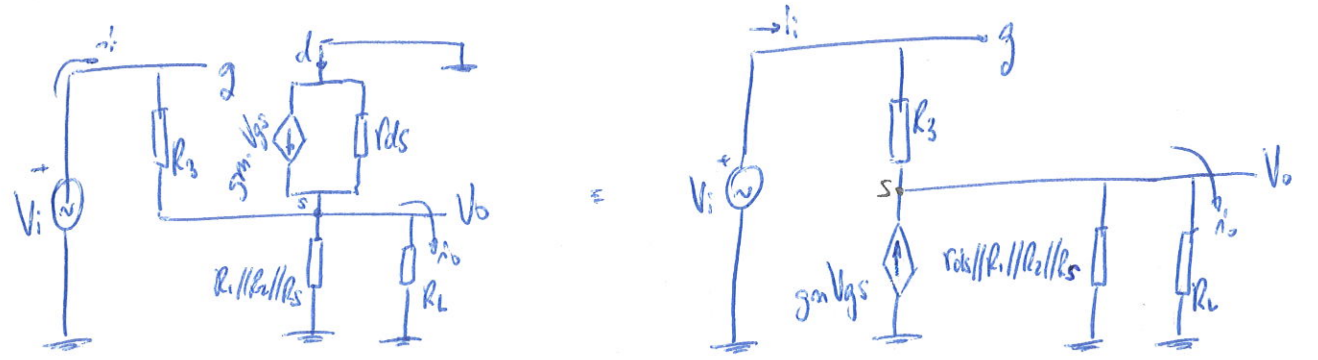
Q ⇒ Podemos calcular parámetros de peq. señal y análisis A.C.

Circuito equivalente en A.C: condensador $\overset{A.C.}{=}$ cortocircuito



= Configuración Drenador Común.

Sustituyendo el MOS



1) $A_V = \dfrac{V_o}{V_i}$

V_{gs} puente entre entrada y salida

$i_i = \dfrac{V_G - V_S}{R_3}$

$V_o = (i_i + g_m V_{gs}) \cdot [R_1 // R_2 // R_S // r_{ds} // R_L]$; $i_i = \dfrac{V_{gs}}{R_3}$ $\quad$ V_o en función de V_{gs} (solamente

$$V_i = V_{gs} + V_o = V_{gs} \cdot \left[1 + \left(\frac{1}{R_3} + g_m\right)\right] \cdot \left[R_1 \| R_2 \| R_3 \| r_{ds} \| R_L\right]$$

$$A_V = \frac{V_o}{V_i} = \frac{\left(\frac{1}{R_3} + g_m\right) \cdot \left[R_1 \| R_2 \| R_3 \| r_{ds} \| R_L\right]}{1 + \left(\frac{1}{R_3} + g_m\right) \cdot \left[R_1 \| R_2 \| R_3 \| r_{ds} \| R_L\right]} = 0'863$$

2/

$$A_i = \frac{i_o}{i_i} = \frac{V_o / R_L}{V_i / Z_i} \underset{3/}{=} A_V \cdot \frac{Z_i}{R_L} = 0'863 \cdot \frac{14'63\ M\Omega}{82\ K\Omega} = 154$$

↑ 3/

Ganancia de entrada elevada.

$Z_i \uparrow$ lleva a $A_i \uparrow$ pues chupa poca corriente al circuito.

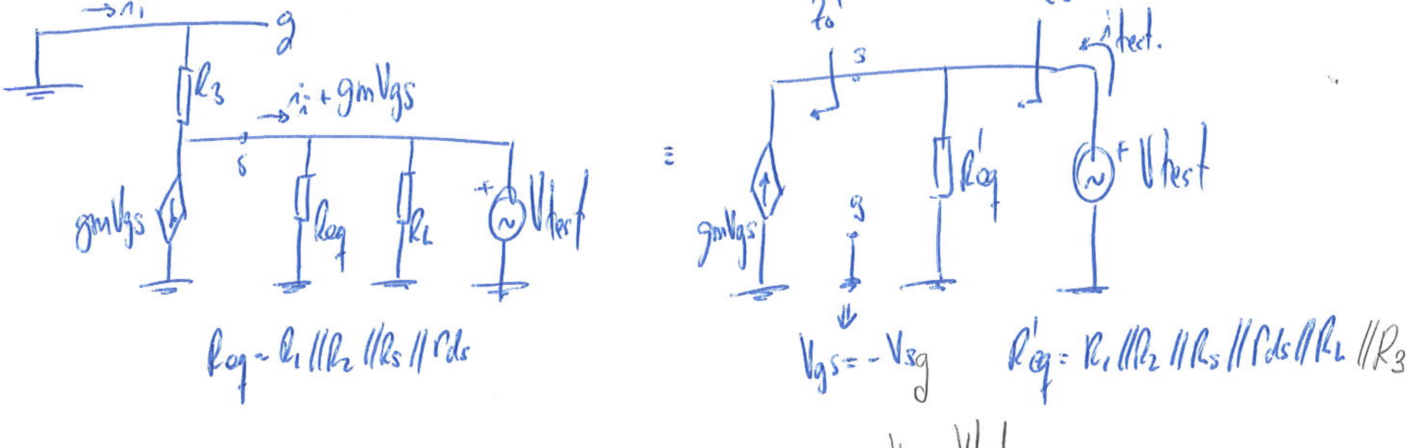
3/ Z_i?

$$Z_i = \frac{V_i}{i_i} = \frac{V_{gs}\left[1 + \overbrace{\left(\frac{1}{R_3} + g_m\right)}^{A} \cdot \overbrace{\left[R_1 \| R_2 \| R_3 \| r_{ds} \| R_L\right]}^{B}\right]}{\frac{V_{gs}}{R_3}} = 14'63\ M\Omega$$

$= V_{gs}(1 + A \cdot B)$

$Z_i > R_3$

4/ Z_o?



$V_{sg} = V_{test}$

$i_{test} = -g_m V_{gs}$

$$z_o' = \frac{V_{test}}{i_{test}} = \frac{V_{test}}{-g_m V_{gs}} \overset{V_{gs}=-V_{test}}{=} \frac{1}{g_m} \Rightarrow z_o = z_o' // R_{eq}' = 0'9\ k\Omega$$

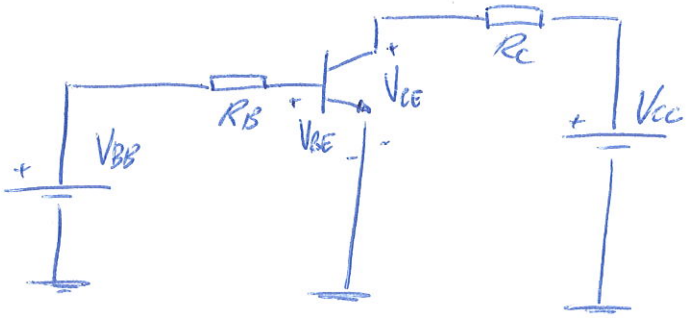
↑ para el cálculo de z_o', R_{eq}' superflua.

$$g_m = \left.\frac{\partial i_D}{\partial V_{GS}}\right|_Q = \frac{-2 I_{DSS}}{V_P}\left(1 - \frac{V_{GSQ}}{V_P}\right) = 0'965\ \frac{mA}{V}$$

— Etapas amplificadoras básicas —

Redes de polarización para BJT.

A) Red de polarización con 2 fuentes de alimentación



Supondremos activa: $V_{BEQ} = 0'7V$

$$I_{BQ} = \frac{V_{BB} - 0'7}{R_B} \qquad V_{BEQ} = -I_{BQ} R_B + V_{BB}$$

Análisis: $I_{CQ} = \underset{h_{FE}}{\beta} \cdot \underbrace{\frac{V_{BB} - 0'7V}{R_B}}_{I_B}$

Diseño: $\left\{ \begin{matrix} I_{CQ} \\ V_{CEQ} \end{matrix} \right\} \Rightarrow \left\{ \begin{matrix} R_C = \dfrac{V_{CC} - V_{CEQ}}{I_{CQ}} \\ R_B = \dfrac{V_{BB} - 0'7}{I_{CQ}/h_{FE}} \end{matrix} \right.$

$$V_{CEQ} = V_{CC} - I_{CQ} \cdot R_C$$

* Ejemplo

Diseñar la pol. a 25°C

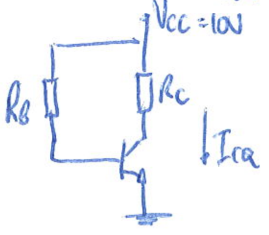
Analizarla a 105°C

Q deseado $\left\{ \begin{matrix} V_{CEQ} = 5V \\ I_{CQ} = 4mA \end{matrix} \right.$

$\beta(25°C) = 60 \qquad \beta(105°) = 120 \qquad$ Valor típico: $\dfrac{\Delta V_{BEQ}}{\Delta T} = -\dfrac{2mV}{°C}$

Diseño:

Tomando $V_{BEQ_{25°C}} = 0'7$



$$R_B = \frac{\overset{V_{CC}}{10} - 0'7}{\frac{4mA}{60}} = 139'5k\Omega \qquad \frac{4mA}{60} = I_{BQ} = 66'6\mu A \qquad I_{BQ} = \frac{I_{CQ}}{\beta}$$

$$R_C = \frac{\overset{V_{CC}}{10} - \overset{V_{CEQ}}{5}}{\underset{I_{CQ}}{4mA}} = 1'25k\Omega$$

Análisis a 105ºC:

ΔV_{BEQ}? $V_{BEQ} = 0'7V + \frac{\Delta V_{BE}}{\Delta T} \cdot \Delta T = \underline{0'54V}$

(0'7V ↑ 25ºC; $\frac{\Delta V_{BE}}{\Delta T}$ ||| $-2mV/ºC$; ΔT ||| (105-25))

Ahora $I_{BQ} = \frac{10 - 0'54}{R_B} = 67'8\,\mu A$ antes $66'6\mu A$, varía poco.

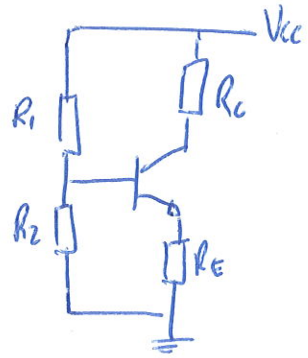
(R_B ||| 139'5K)

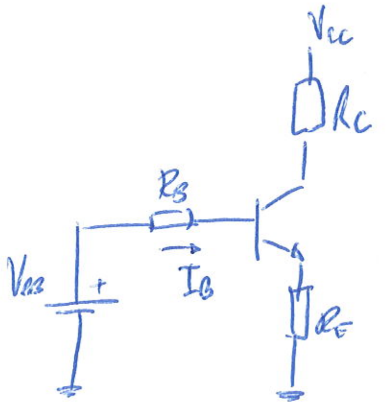
$I_{CQ} = \beta \cdot I_{BQ} = 120 \cdot 67'8_{\mu} = 8'13\,mA$ Varía mucho, la red fija poco Q.

$V_{CEQ} = 10V - I_{CQ} \cdot R_C \Rightarrow 8'13m \cdot 1'25K > 10 \Rightarrow$ SAT. Posiblemente no amplifique.

(||| 10'17)

b) Circuito autopolarizado





$V_{BB} = V_{cc} \frac{R_2}{R_1 + R_2}$

$R_B = R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2}$

Análisis $I_{BQ} = \frac{V_{BB} - V_{BEQ}}{R_B + (h_{FE}+1) R_E}$

$V_{BB} = I_{BQ} \cdot R_B + V_{BEQ} + I_{EQ} R_E$

$I_{EQ} = (h_{FE}+1) I_{BQ}$

$I_{CQ} = h_{FE} \cdot I_{BQ} = \frac{V_{BB} - V_{BEQ}}{\frac{R_B}{h_{FE}} + \frac{h_{FE}+1}{h_{FE}} R_E}$ ($\frac{h_{FE}+1}{h_{FE}} \simeq 1$)

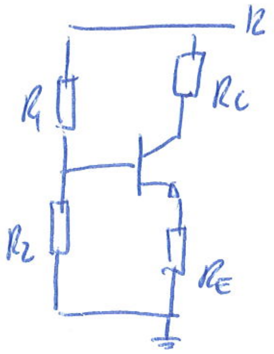
$V_{CEQ} = V_{cc} - I_{CQ}(R_E + R_C)$

$V_{cc} = I_{CQ} R_C + V_{CEQ} + I_{EQ} R_E$

$I_{EQ} \simeq I_{CQ}$

Diseño: $R_E \geq 10 \cdot \frac{R_B}{h_{FE}}$

* Ejemplo:



Datos: $V_{BE}(25°C) = 0'7V$

$\frac{\Delta V_{BE}}{°C} = -\frac{2mV}{°C}$

$Q \begin{cases} V_{CEQ} = 5V > 0'2 \\ I_{CQ} = 4mA > 0 \end{cases}$ → ACTIVA

$h_{FE}(25°C) = 60 \qquad h_{FE}(105°C) = 120$

Diseñar la red de polarización para el Q a 25C.

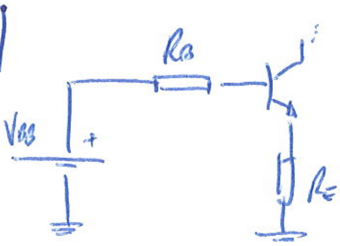
Obtenemos: $R_C + R_E = \frac{\overset{V_{CC}}{12} - \overset{V_{CEQ}}{5}}{\underset{I_{CQ}}{4mA}} = 1'75\,k\Omega$

I_{BQ} fijado por Q: $I_{BQ} = \frac{I_{CQ}}{h_{FE}} = 66'67\,\mu A$

Obs: $I_{EQ} = \underset{4mA}{I_{CQ}} + \underset{66'6\mu A}{I_{BQ}} \simeq \underset{4mA}{I_{CQ}}$

Según criterio de diseño: $R_B \leq \frac{h_{FE} \cdot \overset{1K}{R_E}}{10} = 6K$ tomamos $R_E = 1K$ ya que $R_C + R_E = 1'75K$.

$R_B = 6K$



$V_{BB} = \overset{66'67\mu}{I_B} \cdot \underset{6K}{R_B} + \overset{0'7}{V_{BEQ}} + \underset{4m}{I_{EQ}} \cdot \underset{1K}{R_E} = 5'1\,V$

Hemos calculado $\overset{0'75K}{R_C}, \overset{1K}{R_E}$

$\underset{5'1}{V_{BB}}, \underset{6K}{R_B} \Rightarrow R_1, R_2$

$$V_{BB} = V_{CC}\frac{R_2}{R_1+R_2} \qquad 5'1 = 12\frac{R_2}{R_1+R_2}$$

$$R_B = \frac{R_1 R_2}{R_1+R_2} \qquad 6K = \frac{R_1R_2}{R_1+R_2}$$

$$\left.\right\} \quad R_1 = 14'12K \quad R_2 = 10'43K$$

Análisis a 105°C

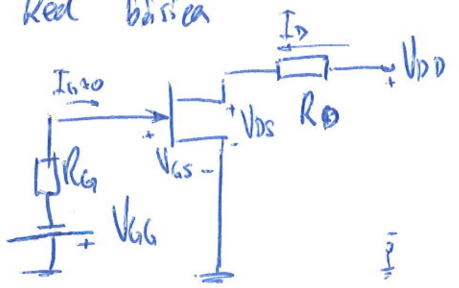
Ahora: $I_{BQ} = \dfrac{\overset{V_{BB}}{5'1} - \overset{V_{BEQ}(105)}{0'54}}{6K + 120 \cdot 1K} = 36'2\,\mu A$ la mitad que a 25°C, no es malo.

$I_{CQ} = 120 \cdot 36'2\,\mu A = 4'3\,mA$ antes 4'3 mA, varía poco -10%.

$V_{CEQ} = \underset{V_{CC}}{12} - \overset{I_{CQ}}{4'34}(\underset{R_C}{0'75} + \underset{R_E}{1K}) = 4'4V$ (12%)

Redes de polarización para FET.

A) Red básica



→ JFET, válido también para MOS vaciamiento, con MOS acumulación cambia el signo de V_{GG}.

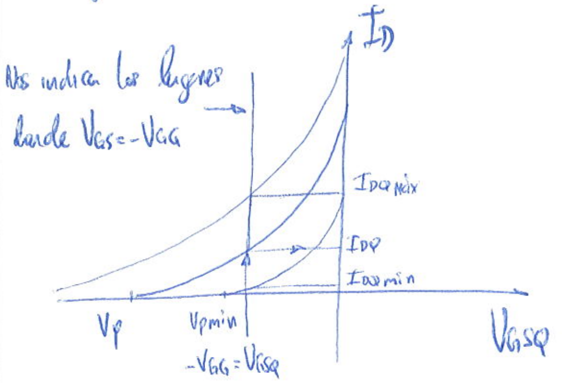
Análisis: $V_{GS} = -V_{GG}$ $\boxed{I_G \simeq 0}$

SAT: $I_D = I_{DSS}\left(1 - \dfrac{\overset{-V_{GG}}{V_{GS}}}{V_P}\right)^2$

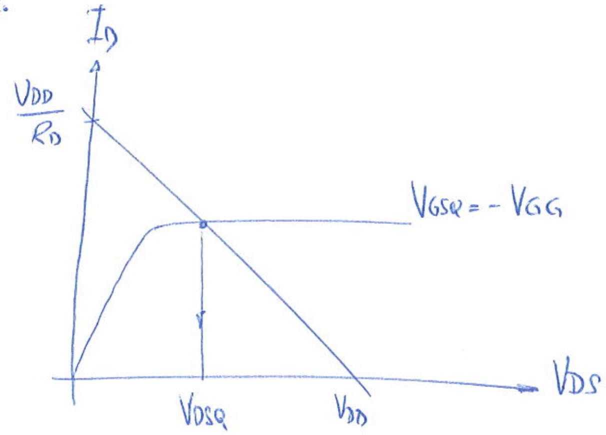
$V_{DSQ} = V_{DD} - I_D R_D$

Gráficamente:

Caract. de Transf.

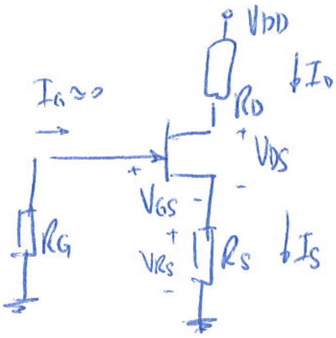


V_{GSQ} →



B/ Circuito autopolarizado

* Válido sólo para JFET y MOS vaciamiento.
no para MOS acumulación.



$V_S > 0$

$V_G = 0$ pues $I_G \simeq 0$

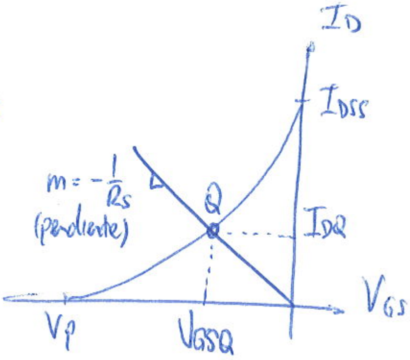
$\Bigg\} \Rightarrow V_{GS} < 0 \Rightarrow$ JFET en conducción.

$I_S \simeq I_D$

Análisis:

Malla G-S: $\quad I_{DQ} = -\dfrac{V_{GSQ}}{R_S} \qquad I_S R_S = -V_{GS}$

Característica del FET: $\quad I_{DQ} = I_{DSS}\left(1 - \dfrac{V_{GSQ}}{V_p}\right)^2$



Malla D-S: $\quad V_{DSQ} = V_{DD} - I_{DQ} R_D - \overset{I_{SQ}}{\overset{\shortparallel}{I_{DQ}}} R_S = V_{DD} - I_{DQ}(R_D + R_S)$

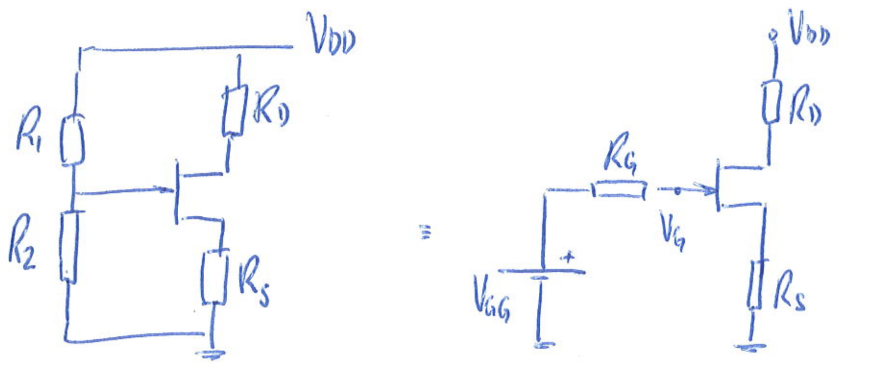
$(V_{DD} = I_{DQ} R_D + V_{DSQ} + I_{SQ} R_S)$

Diseño:

se nos da Q deseado: $\left\{\begin{matrix} I_{DQ} \\ V_{DSQ} \end{matrix}\right\} \Rightarrow$ hallamos V_{GSQ}

$I_{DQ} = I_{DSS}\left(1 - \dfrac{V_{GSQ}}{V_p}\right)^2$ hallamos $R_S = -\dfrac{V_{GSQ}}{I_{DQ}} \rightarrow R_D = \dfrac{V_{DD} - V_{DSQ}}{I_{DQ}} - R_S$

c) Mejoramos polarización mediante el circuito:



$V_G = V_{GG} > 0$
y
$I_G \simeq 0$

Análisis:

$$V_{GS} = V_{GG} - I_D R_S \Rightarrow I_{DQ} = \frac{V_{GG} - V_{GSQ}}{R_S}$$

$$I_{DQ} = I_{DSS}\left(1 - \frac{V_{GSQ}}{V_P}\right)^2$$

$$V_{DSQ} = V_{DD} - I_{DQ}(R_D + R_S)$$ y comprobamos SAT.

Diseño: Escogemos I_{DQ}.

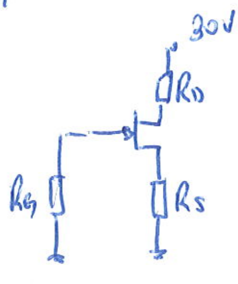
* Ejemplo:
diseñar la red de polarización

Q deseado: $\begin{cases} I_{DQ} = 1mA \\ V_{DSQ} = 15V \end{cases}$ $V_{DD} = 30V$ Características del FET:

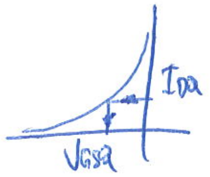
	máx	TYP	mín
I_{DSS} (1)	5mA	2'8mA	1mA
V_P	-2'3V	-1'25V	-0'6V

(1) $I_{DSS_{máx}} > I_{DQ}$ deseada

Diseño:
a) Circuito autopolarizado



- V_{GSQ} está fijado por Q.



- $\underset{1mA}{I_{DQ}} = \overset{2'8mA}{I_{DSS}}\left(1 - \frac{V_{GSQ}}{\underset{-1'25V}{V_P}}\right)^2 \Rightarrow V_{GSQ} = -0'5V$

$$V_{GSQ} = V_P\left(1 - \sqrt{\frac{I_{DQ}}{I_{DSS}}}\right)$$

- $R_S = ?$ $\quad R_S = \frac{-V_{GSQ}}{I_{DQ}} = \underline{0'5\ K\Omega}$ (Malla G-S)

- $R_D = ?$ $\quad \underset{0'5\,K\Omega}{R_S} + R_D = \frac{\overset{30V}{V_{DD}} - \overset{15V}{V_{DSQ}}}{\underset{1mA}{I_{DQ}}}$ (KVL en D-S)

$$\underline{R_D = 14'5\ K\Omega}$$

Análisis: Caso máximo y caso mínimo:

- máximo

$$\left.\begin{array}{l} I_{DQ} = -\frac{V_{GSQ}}{0'5K\Omega} \\ I_{DQ} = \underset{I_{DSSmáx}}{5mA}\left(1 - \frac{V_{GSQ}}{\underset{V_{pmáx}}{-2'3}}\right)^2 \end{array}\right\} \Rightarrow \begin{array}{l} V_{GSQ} = -0'91\,V \\ I_{DQ} = 1'823\ mA \quad (+82\%) \end{array}$$

$$V_{DSQ} = \underset{V_{DD}}{30} - \underset{1'823mA}{I_{DQmáx}}(\overset{14'5K}{R_D} + \overset{0'5K}{R_S}) = 2'65\,V \quad (-82\%)$$

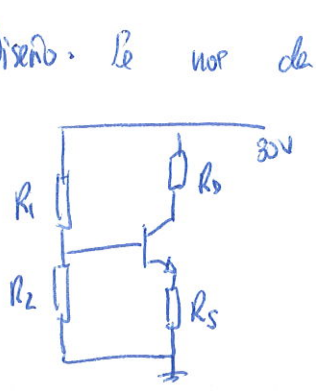
- se verifica SAT. por poco: $\underset{2'65V}{V_{DSQ}} \geq \underset{-0'91V}{V_{GSQ}} - \underset{-(-2'3V)}{V_p}$

- mínimo.

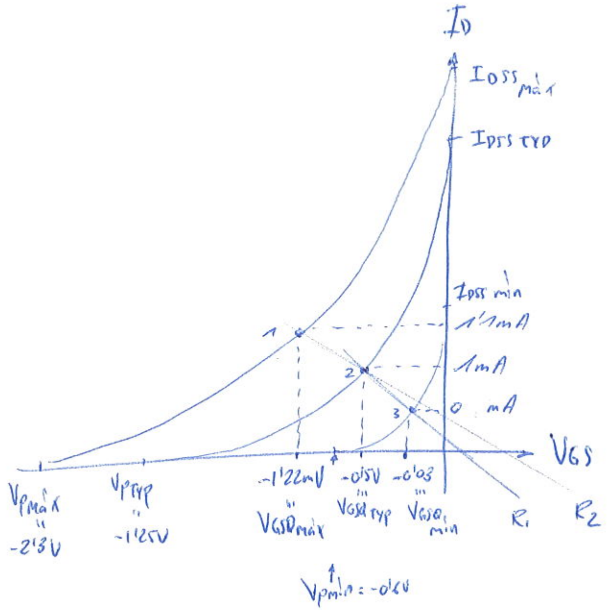
Analogamente:
$V_{GSQ} = -0'21V$
$I_{DSQ} = 0'42\,mA \quad (-58\%)$
$V_{DSQ} = 23'7\,V \quad (+58\%)$

o sea, Q poco estable.

Diseño. Se nos da $\Delta I_{DQ} \Rightarrow$ Q tendrá la estabilidad deseada.



$\Delta I_{DQ} = \pm 10\%\ I_{DQ} = \pm 0'1\ mA$



Recta 1 (puntos 2-3)

Recta 2 (puntos 1-2)

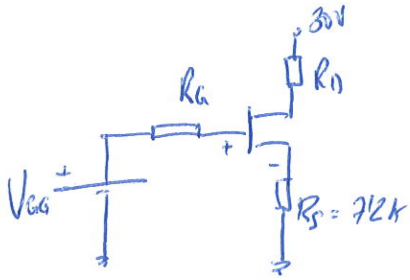
Calculamos las pendientes:

$$m_1 = \frac{1mA - 0'9\,mA}{-0'5-(-0'03)} = -0'21\ \frac{mA}{V} \Rightarrow R = -\frac{1}{m_1} = 4'7\ K\Omega$$

$$m_2 = \frac{1'1mA - 1mA}{-1'22-(-0'5)} = -0'138\,\frac{mA}{V} \Rightarrow R_S = -\frac{1}{m_2} = 7'2\,K\Omega$$

Tomamos la recta de pendiente más plana $\left\{ \begin{matrix} |m| \downarrow \\ m \uparrow\ (m<0) \end{matrix} \right\}$ o sea $m_2 \Rightarrow \boxed{R_S = 7'2K}$

$R_1, R_2 = ?$ Las hallamos a través de R_G, V_{GG}



$$V_{GG} = \underset{\simeq 0}{I_G} \cdot R_G + \underset{-0'5V}{V_{GSQ}} + \underset{+1mA}{I_{DQ}} \cdot \overset{7'2K}{R_S} = 6'7V$$

$R_G = ?$ $R_G = 1M\Omega$ pues $I_G R_G \downarrow\downarrow$

$\left.\begin{matrix} R_G = 1M\Omega \\ V_{GG} = 6'7V \end{matrix}\right\} \rightarrow \left\{ \begin{matrix} R_1 = 4'48\ M\Omega \\ R_2 = 1'29\ M\Omega \end{matrix} \right.$

$$R_G = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

$$V_{GG} = 30V \cdot \frac{R_2}{R_1 + R_2}$$

Comprobación del circ. pol:

1. $FET_{TYP.}$ se cumple el Q deseado $I_{DQ} = 1mA$ $V_{DSQ} = 15V$

2. $FET_{máx}$:

$I_{DQ_{máx}} = 1'1\ mA$ (+10%)

$V_{GSQ} = -1'22\ V$ (+144%) No importa.

$V_{DSQ} = 13'5\ V$ (-10%)

3. $FET_{mín}$:

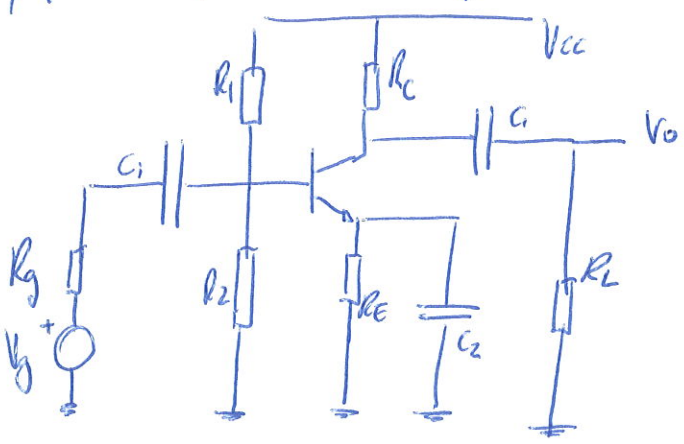
$I_{DQ} = 0'93\ mA$ (-7%)

$V_{GSQ} = -0'02\ V$ (-96%)

$V_{DSQ} = 16V$ (-16'67%)

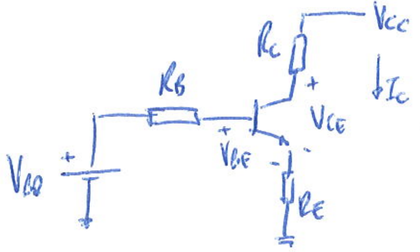
Márgenes dinámicos.

Ejemplo: para bipolar aplicable a FET.

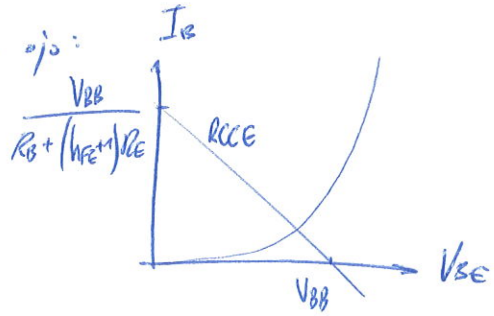


← EC.

A/ Circuito de polarización:

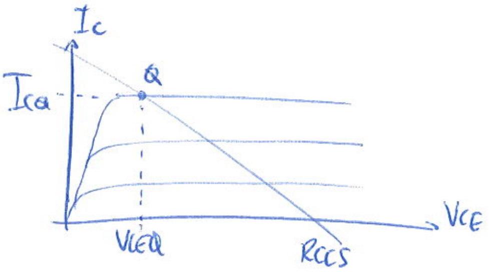


Visión a ojo:



RCCS: $\left(V_{CC} = I_C R_C + V_{CE} + I_E R_E\right)$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C + R_E}$$



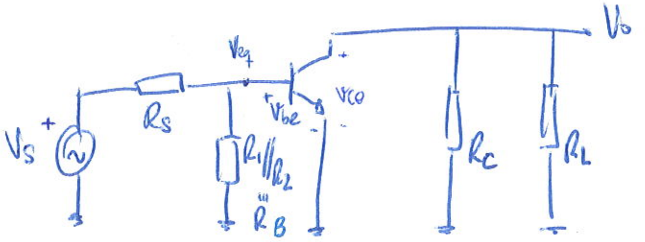
RCCE: $\left(V_{BB} = I_B R_B + V_{BE} + I_E R_E\right)$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B + (h_{FE}+1) R_E}$$

$h_{FE} = \beta$

$I_E = (\beta+1) I_B$

B/ Obtención de la RCA:



$$V_{eq} = V_s \frac{R_B}{R_S + R_B}$$

$$R_{eq} = R_S \parallel R_B$$

RCAE: $i_b = \dfrac{V_{eq} - v_{be}}{R_{eq}}$ $\qquad \dfrac{\partial i_b}{\partial v_{be}} < 0$

RCAS: $i_c = \dfrac{-v_{ce}}{R_C \parallel R_L}$ $\Leftarrow$ $v_{ce} = -i_c \left(R_C \parallel R_L\right)$ $\qquad \dfrac{\partial i_c}{\partial v_{ce}} < 0$

$$\begin{cases} V_{BE} = V_{BEQ} + v_{be} \\ i_B = I_{BQ} + i_b \end{cases} \qquad \begin{cases} V_{CE} = V_{CEQ} + v_{ce} \\ i_C = I_{CQ} + i_c \end{cases}$$

$$i_B - I_{BQ} = \frac{V_{eq} - V_{BE} + V_{BEQ}}{R_{eq}}$$

$i_b = \dfrac{V_{eq} - v_{be}}{R_{eq}}$ (RCAE)

RCAE: $i_B = \left(I_{BQ} + \dfrac{V_{BEQ}}{R_{eq}} + \dfrac{V_{eq}}{R_{eq}} \right) - \dfrac{V_{BE}}{R_{eq}}$

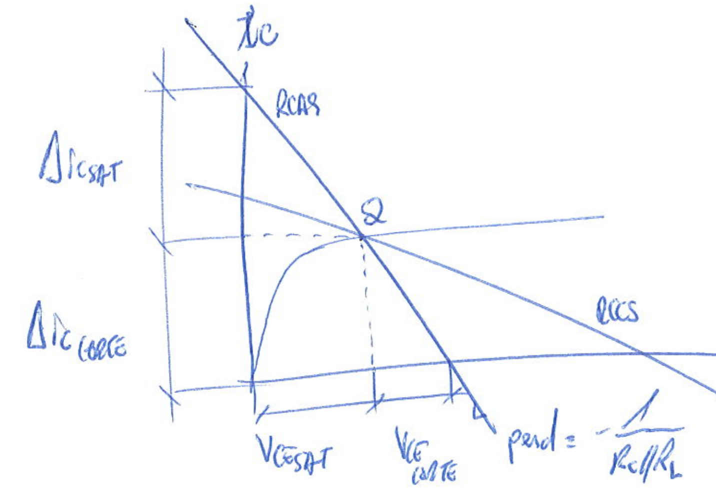
$i_B = I_{BQ} + i_b$ — i_b (RCAE)

cambio variable i_B / V_{BE}

$i_c = \dfrac{-v_{ce}}{R_C // R_L}$ (RCAS)

RCAS: $i_C = \left(I_{CQ} + \dfrac{V_{CEQ}}{R_C // R_L} \right) - \dfrac{V_{CE}}{R_C // R_L}$ — i_c (RCAS)

$i_C = I_{CQ} + i_c$



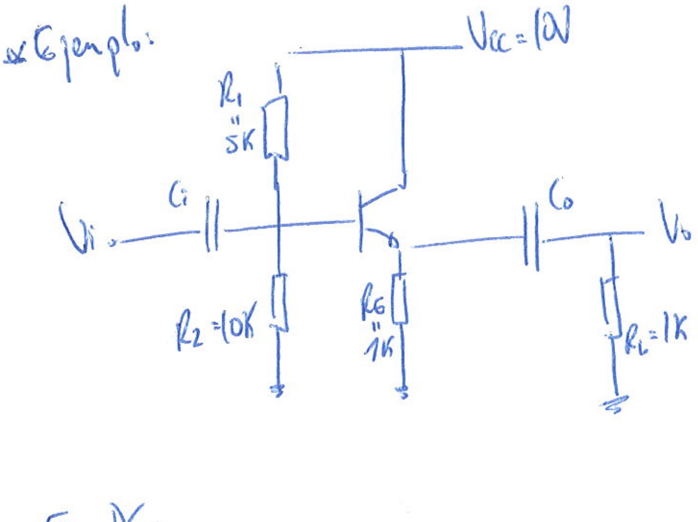
$$\Delta V_{CE} = \Delta V_{CESAT} + \Delta V_{CE\,CORTE}$$

$\Delta V_{CESAT} = V_{CEQ} - V_{CESAT}$; $\Delta V_{CE\,CORTE} = I_{CQ} / |pend|$

$$\Delta i_C = \Delta i_{CSAT} + \Delta i_{C\,CORTE}$$

$\Delta i_{CSAT} = (V_{CEQ} - V_{CESAT}) |pend|$; $\Delta i_{C\,CORTE} = I_{CQ}$

* Ejemplo:

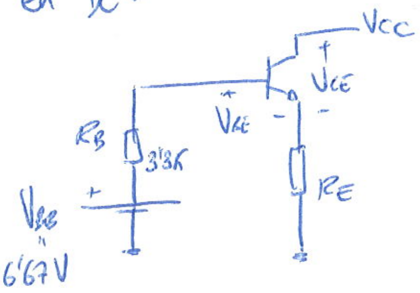


$V_{BE\,ACT} = 0'7V$ $\qquad h_{FE} = h_{fe} = 100$

$V_{CESAT} = 0'5V$ $\qquad h_{ie} = 1K$

— Colector Común (CC)

En DC:



RCCE: $I_B = \dfrac{V_{BB} - V_{BE}}{R_B + (h_{FE}+1) R_E}$ $\quad \left(V_{BB} = I_B R_B + V_{BE} + I_E R_E \right)$

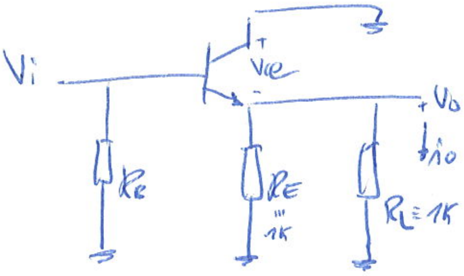
$I_E = (h_{FE}+1) I_B$

RCCS: $I_C = \dfrac{V_{CC} - V_{CE}}{R_E}$; $I_C = h_{FE} \cdot I_B$

$V_{BB} = 10 \cdot \dfrac{10K}{10K + 5K}$ $\qquad R_B = \dfrac{10K \cdot 5K}{10K + 5K}$

Q sería $\begin{cases} I_{CQ} = 5'72\ mA \\ V_{CEQ} = 4'28\ V \end{cases}$

En AC:



$$R_E // R_L = \frac{R_E \cdot R_L}{R_E + R_L} = \frac{1K \cdot 1K}{2K} = \frac{1}{2}K = 500\Omega$$

$$pend = -\frac{1}{R_E // R_L} = -\frac{1}{500\Omega} = -2\,m℧$$

RCAS → $i_c(V_{ce})$

$$V_{ce} = -V_o = -i_c(R_E//R_L) \Rightarrow i_c = -\frac{V_{ce}}{R_E//R_L} \qquad i_c = i_e$$

KVL: $V_{ce} + \underset{V_o}{i_c(R_E//R_L)} = 0$

$$\Delta V_{CESAT} = \underset{4'28V}{V_{CEQ}} - \underset{0'5V}{V_{CESAT}} = 3'78V \qquad \Delta V_{CE_{CORTE}} = \frac{I_{CQ}}{|Pendiente|} = \underset{5'72mA}{I_{CQ}} \cdot \underset{500\Omega}{R_E//R_L} = 2'86\,V.$$

↖ (Valor absoluto)

$$\Delta i_{CSAT} = \underset{3'78V}{(V_{CEQ} - V_{CESAT})} \cdot \underset{2m℧}{|pend|} = 7'56\,mA \qquad \Delta i_{C_{CORTE}} = I_{CQ} = 5'72\,mA$$

* Margen dinámico de tensión: $\Delta V_{CE} = \underset{3'78}{\Delta V_{CESAT}} + \underset{2'86}{\Delta V_{CE_{CORTE}}} = 6'64\,V$

* MES tensión: $MES(V_{CE}) = 2 \times \text{minimo}(\Delta V_{CESAT}, \Delta V_{CE_{CORTE}}) = 2 \cdot 2'86 = 5'72\,V$ p-p

* Margen dinámico de corriente: ~~$\Delta i_C = \Delta i_{CSAT} + \Delta i_{C_{CORTE}}$~~

$$\Delta i_C = \frac{\Delta V_{CE}}{R_L} = \frac{6'64V}{1K} = 6'64\,mA$$

* MES corriente: ~~$MES(i_C) = 2 \times \text{minimo}(\Delta i_{CSAT}, \Delta i_{C_{CORTE}})$~~

$$MES(i_C) = \frac{MES(V_{CE})}{R_L} = \frac{5'72V}{1K} = 5'72\,mA \text{ p-p}$$

MES óptima: A partir de R_1 y R_2.

COND. 1

$\Delta V_{CESAT} = \Delta V_{CECRTE} \longrightarrow V_{CEQ} - V_{CESAT} = \frac{I_{CQ}}{|pend.|} = I_{CQ} \cdot R_E // R_L$

(V_{CEQ} ?, I_{CQ} ?)

COND. 2 $Q \in RCCS$

$V_{CC} = V_{CEQ} + I_{EQ} \cdot R_E$

(V_{CEQ} ?, $I_{EQ} = I_{CQ}$?)

Resolviendo las 2 ecuaciones: $Q \equiv \begin{cases} V_{CEQ} = 3'67\,V \\ I_{CQ} = 6'33\,mA \end{cases}$

El nuevo Q cumple que estamos en Activa:

$V_{CEQ} > 0'5\,V = V_{CESAT}$

Debemos hallar R_1, R_2 a partir de R_B y V_{BB}

V_{BB}?

R_B?

$I_{BQ} = \frac{I_{CQ}}{h_{FE}} = 63'3\,\mu A$ ($I_{CQ} = 6'33\,mA$, $h_{FE} = 100$)

1. $I_{BQ} = \frac{V_{BB} - V_{BEQ}}{R_B + (h_{FE}+1) \cdot R_E}$ ($I_{BQ} = 63'3\,\mu A$, $V_{BEQ} = 3'67\,V$, $h_{FE} = 100$, $R_E = 1K\Omega$) $\qquad h_{FE}+1 \approx h_{FE}$

2. $h_{FE} \cdot R_E \gg R_B$ ($h_{FE} \approx (h_{FE}+1)$) $\rightarrow h_{FE} \cdot R_E = 10\,R_B$ ($h_{FE} \cdot R_E = 100K$) $\rightarrow$ $\boxed{R_B = 10K\Omega}$

(1) $\rightarrow$ $\boxed{V_{BB} = 7'73\,V}$

$R_B = 10 K\Omega$
$V_{BB} = 7'73 V$ } ⇒ $V_{BB} = V_{CC} \frac{R_2}{R_1 + R_2}$; $R_B = R_1 // R_2$ ⇒ { $R_1 = 12'9 K\Omega$; $R_2 = 44 K\Omega$ }

Con esto MES es máxima.

MES de V_o = MES de $V_{CE} = 2 \cdot \Delta V_{CE} = 2 \cdot (3'67 - 0'5) = \underline{6'34 V}$

($3'67$ = V_{CEQ}, $0'5$ = V_{CESAT})

máxima oscilación en la salida sin distorsión.

Diseño de 1 etapa amplificadora en EC

- Especificaciones:

$|A_V| = 100$ · sabemos que en EC $A_V < 0$ $\Rightarrow$ $A_V = -100$

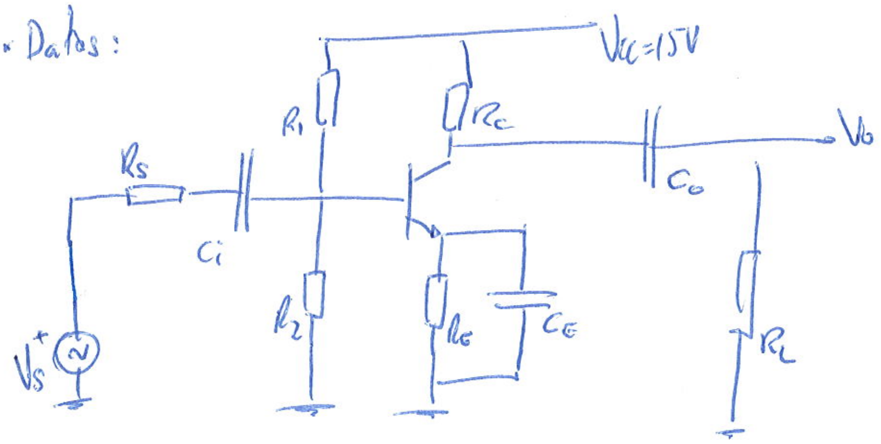
$|V_i| \leq 4mV_{p-p}$ $\Rightarrow$ MES = $80mV_{p-p}$ · A_V = $8V_{p-p}$

$V_{CC} = 15V$

$R_L = 10 K\Omega$

Q estable ante h_{FE}

- Datos:



BJT: $h_{ie\,typ} = 4'5K\Omega$

$h_{FE\,TIP} = 330$ AC (= pequeña señal)

$h_{FE} = 230_{min}, 290_{tip}, 520_{máx}$ DC

$V_{BE\,ACT} = 0'62V$ $V_{CE\,SAT} = 0'2V$

Diseñar: R_1, R_2, R_C, R_E

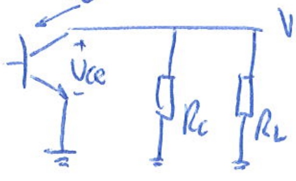
- Introducción márgenes seguridad:

1. $V_{CE\,SAT} = 0'2V + 0'8V = 1V$

2. se nos pide MES = 8V, diseñaremos 10% de más, o sea 8'8V.

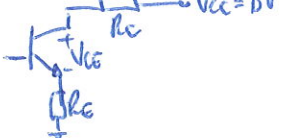
- Analizando en AC y DC obtenemos las RCA y RCC:

RCAS:



$V_o = V_{ce} = -i_c \cdot R_C // R_L$ $\qquad i_c = -\dfrac{V_{ce}}{R_C // R_L}$

RCCS:



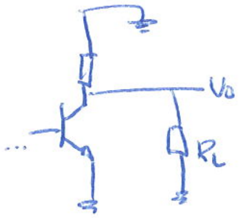
$V_{CC} = I_C R_C + V_{CE} + I_E R_E$ $\qquad V_{CEQ} = V_{CC} - I_C (R_E + R_C)$

- Condición 1: MES máxima $\Rightarrow$ $\Delta V_{CESAT} = \Delta V_{CE\,corte}$

$$\frac{8'8}{2} = \frac{MES}{2} = V_{CEQ} - V_{CESAT} = I_{CQ} \cdot R_C // R_L$$

(V_{CEQ} ?, $V_{CESAT} = 1V$, I_{CQ} ?, $R_C//R_L$?)

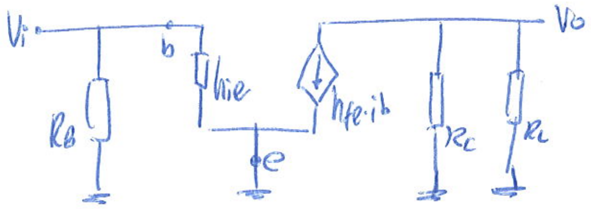
en pequeña señal: $V_o = V_{ce} \Rightarrow$ Márgenes V_o = márgenes V_{ce}



- Condición 2: Analizamos el resto de especificaciones:

Obtención de la ganancia:

El circuito equivalente en AC es:



$$\left.\begin{array}{l} V_o = -h_{FE} i_b \cdot R_C//R_L \\ V_i = i_b \cdot h_{ie} \end{array}\right\} \rightarrow A_v = \frac{v_o}{v_i} = -\frac{h_{fe} \cdot R_C//R_L}{h_{ie}}$$

$A_v (= -100)$ $R_C = ?$

$$\frac{R_C \cdot R_L}{R_C + R_L} = \frac{A_v \cdot h_{ie}}{-h_{FE}} = 1'36\,K\Omega$$

($A_v = -100$, $h_{ie} = 4'5K\Omega$, $h_{FE} = 330$)

$$R_C = 1'36\,K\Omega \,//\, -R_L = 1'58\,K \simeq 1K5$$

($R_L = 10K$)

$R_E = ?$ A partir de la RCCS:

$$I_{CQ} = \frac{V_{CC} - V_{CEQ}}{R_C + R_E} \quad \text{y} \quad V_{CEQ} = \Delta V_o + V_{CESAT}$$

$V_{CEQ} - V_{CESAT} = \Delta V_o$ (cond. 1)

también: Cond. 1 $\quad \Delta V_o = I_{CQ}\ R_C//R_L$

($\Delta V_o = 4'4V$, $R_C = 1k\Omega$, $R_L = 10k\Omega$)

Aislando:

$$\Delta V_o = \frac{(\overset{15V}{V_{CC}} - V_{CESAT})\, R_C // R_L}{\underset{1K2}{R_E} + \underset{1K5}{R_C} + \underset{1'5K}{R_C // R_L}} = 4'56\ V_p \quad \text{(voltios de pico)}$$

$$R_E = \frac{(V_{CC} - V_{CESAT})\, R_C // R_L}{\Delta V_o} - R_C // R_L - R_C = \underline{1'35K} \approx 1K2$$

Diseño

De $\underset{4'56V}{\Delta V_o}$ hallamos Q: $\Delta V_o = I_{CQ}\,(R_C // R_L) \Rightarrow I_{CQ} = 3'5\ mA$

ΔV_o = 4'56V = $V_{CEQ} - V_{CESAT} = 5'56\ V$

} Q deseado para asegurar MES óptima.

$\left.\begin{matrix} V_{BB} \\ R_B \end{matrix}\right\} \Rightarrow \left\{\begin{matrix} R_1 \\ R_2 \end{matrix}\right\}$?

$$I_{BQ} = \frac{I_{CQ}}{\underset{290}{h_{FETYP}}} = 12\ \mu A$$

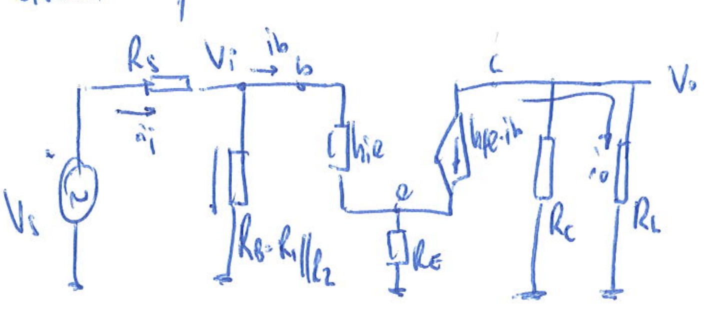
$$I_B = \frac{V_{BB} - \overset{0'62V}{V_{BEQ}}}{R_B + (\underset{290}{h_{FETYP}} + 1)\underset{1K2}{R_E}}$$

; $h_{FEmin} \cdot R_E \gg R_B \rightarrow R_B = \frac{h_{FEmin} \cdot R_E}{10} = 27'6K$

$V_{BB} = 5'14\ V$

A partir de V_{BB} y R_B obtenemos $\left\{\begin{matrix} R_1 = 82K \\ R_2 = 39K \end{matrix}\right.$

Circuito equivalente en AC:



$$V_o = -h_{fe} \cdot i_b\,(R_C // R_L)$$

$$i_o = -h_{fe} \cdot i_b\, \frac{R_C}{R_C + R_C}$$

$$i_i = i_b + \frac{V_i}{R_B} = i_b + \frac{h_{ie} + (h_{fe}+1) R_E}{R_B} \cdot i_b$$

$$V_i = i_b \cdot h_{ie} + I_{RE} R_E = i_b \cdot h_{ie} + \underbrace{i_b\,(h_{fe}+1)}_{I_{RE}} R_E$$

$$\Updownarrow$$

$$V_i = V_{hie} + V_{RE} = i_b \cdot h_{ie} + (i_b + h_{fe} \cdot i_b) R_E$$

* Ganancia de Tensión:

$$A_V = \frac{v_o}{v_i} = -\frac{h_{fe}\,(R_C // R_L)}{h_{ie} + (h_{fe}+1) R_E}$$

$$A_{V_S} = \frac{V_o}{V_S} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_S} = A_V \cdot \underbrace{\frac{Z_i}{Z_i + R_S}}_{V_i/V_S}$$

↑ ganancia de tensión a la entrada.

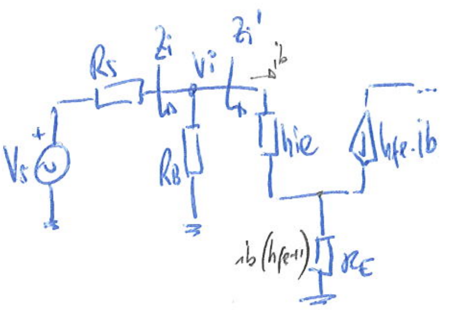
* Ganancia de Corriente:

$$A_i = \frac{i_o}{i_i} = \frac{-h_{fe} \cdot i_b \,\frac{R_C}{R_C + R_L}}{i_b + \frac{h_{ie} + (h_{fe}+1) R_E}{R_B}\, i_b} = \frac{h_{fe} \cdot R_B}{R_B + h_{ie} + (h_{fe}+1) R_E} \cdot \frac{R_C}{R_C + R_L}$$

* Impedancia entrada:

$$Z_i = R_B // \underbrace{\left[h_{ie} + R_E (h_{fe}+1)\right]}_{Z_i'}$$

$Z_i = R_B // Z_i'$

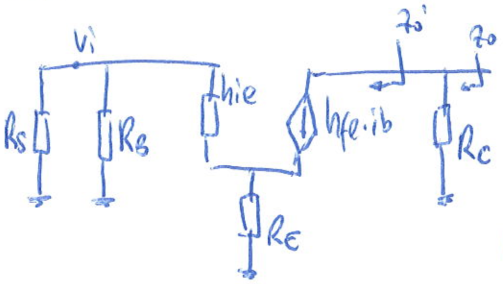


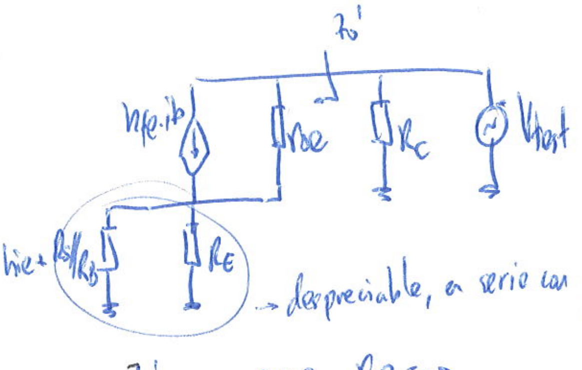
$$Z_i' = \frac{V_i}{i_b} = h_{ie} + (h_{fe}+1) R_E$$

$$V_i = i_b \cdot h_{ie} + i_b\,(h_{fe}+1) \cdot R_E$$

* Impedancia salida:

$Z_o = R_C$



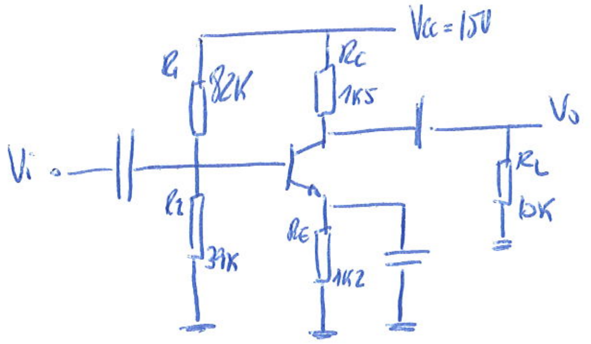


→ despreciable, en serie con fuente corriente.

$Z_o = R_C // Z_o'$

$Z_o' = \infty$ pues $r_{oe} = \infty$

- Verificación del diseño completo:



· Obtención del punto de trabajo = análisis en DC:

$$\begin{cases} V_{BB} = 15 \dfrac{39K}{39K+82K} = 4'83V \\ R_B = 39K \,//\, 82K = \dfrac{39K \cdot 82K}{39K+82K} = 29'43 K\Omega \end{cases}$$

$$Q: \begin{cases} I_{BQ} = \dfrac{V_{BB} - V_{BEQ}}{R_B + (h_{FE_{tip}}+1) R_E} = \dfrac{4'83 - 0'62}{26'43k + 291 \cdot 1'2k} = 11'2 \mu A \\ I_{CQ} = h_{FE_{tip}} \cdot I_{BQ} = 290 \cdot 11'2 \mu A = 3'25 mA \\ V_{CEQ} = V_{CC} - I_{CQ}(R_E + R_C) = 15 - 3'25(1'5k + 1'2k) = 6'23 V \end{cases}$$

· Obteniendo los márgenes dinámicos a partir de las fórmulas vistas en teoría (deducibles de RCAS = Análisis en AC)

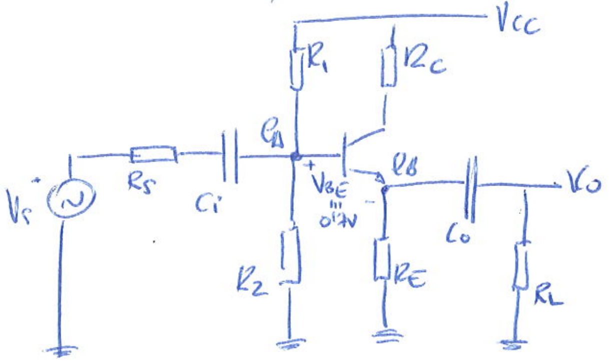
$$\Delta V_{CE_{corte}} = I_{CQ}(R_C // R_L) = 3'25 mA (1k5 // 10k) = 4'24V \quad > 4V \quad ✓$$

$$\Delta V_{CE_{SAT}} = V_{CEQ} - V_{CE_{SAT}} = 6'23V - 1V = 5'23V \quad > 4V \quad ✓$$

· Por lo tanto:

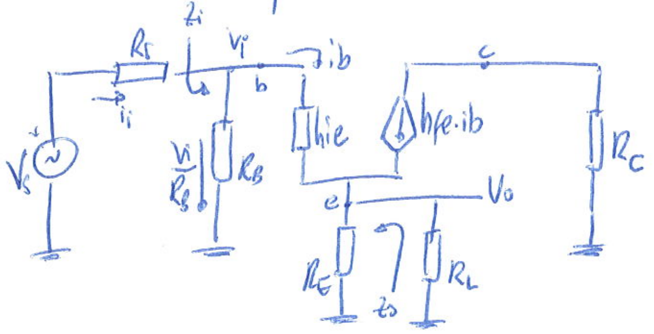
$$MES = 2 \, mínimo(\Delta V_{CE_{corte}}, \Delta V_{CE_{SAT}}) = 2 \times 4'24V = 8'48V$$

Etapa amplificadora en Colector Común



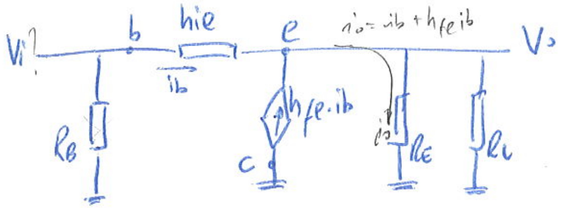
Por simple inspección, la tensión en la salida es menor que en la entrada, en e_B habrán 0'7V menos que en e_A.

En AC y pequeña señal:



* Cálculo de AV:

$$A_V = \frac{V_o}{V_i} = \frac{(h_{fe}+1)\, i_b\, (R_E // R_L)}{h_{ie}\, i_b + (h_{fe}+1)\, i_b\, (R_E // R_L)} = \frac{(h_{fe}+1)(R_E // R_L)}{h_{ie} + (h_{fe}+1)(R_E // R_L)}$$



$$V_o = (h_{fe}+1)\, i_b\, (R_E // R_L)$$

$$V_i = V_{hie} + V_o = h_{ie} \cdot i_b + (h_{fe}+1)\, i_b\, (R_E // R_L)$$

$V_i = i_b h_{ie} + V_o \Rightarrow V_o < V_i \Rightarrow A_V < 1$

$A_V > 0$ no hay inversión de fase, V_i y V_o están en fase.

Normalmente $h_{ie} < (h_{fe}+1)(R_E // R_L) \Rightarrow A_V \approx 1$, se llama Seguidor de Tensión.

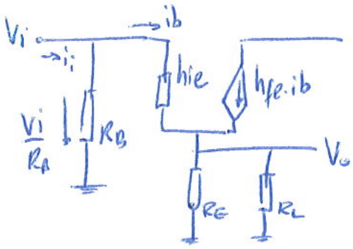
* $A_i = \dfrac{i_b}{i_i} = \dfrac{(h_{fe}+1) R_B}{R_B + h_{ie} + (h_{fe}+1)(R_E // R_L)} \cdot \dfrac{R_E}{R_E + R_L}$

$\dfrac{R_E R_L}{R_E + R_L}$

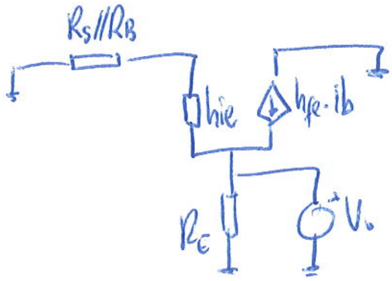
$i_o = (h_{fe}+1)\, i_b \dfrac{R_E}{R_E + R_L} = \dfrac{V_o}{R_L}$ $\quad V_o = (h_{fe}+1)\, i_b \cdot (R_E // R_L)$

$i_i = i_b + \dfrac{V_i}{R_B}$; $V_i = i_b \left[h_{ie} + (h_{fe}+1) \cdot (R_E // R_L) \right]$

* $Z_i = \dfrac{V_i}{I_i} = \dfrac{V_i}{\dfrac{V_i}{R_B} + \dfrac{V_i}{h_{ie} + (h_{fe}+1)(R_E // R_L)}} = R_B // \left[h_{ie} + (h_{fe}+1) \cdot (R_E // R_L) \right]$

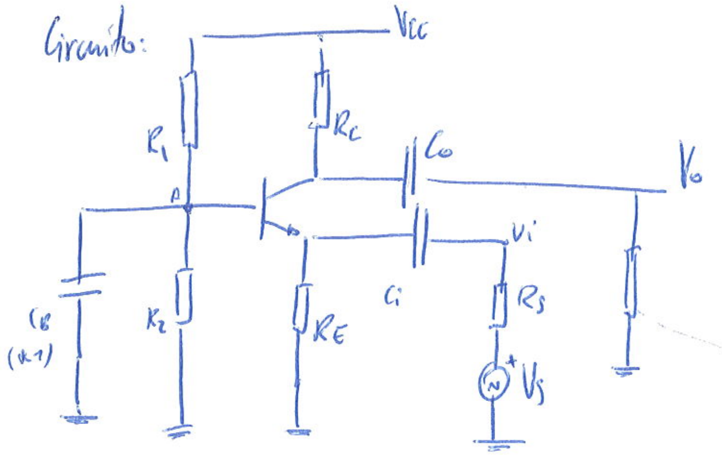


* $Z_o = \dfrac{V_o}{i_o} = \dfrac{V_o}{\dfrac{V_o}{R_E} + (h_{fe}+1)\, i_b} = \dfrac{V_o}{\dfrac{V_o}{R_E} + (h_{fe}+1) \dfrac{V_o}{h_{ie} + R_S // R_B}} = R_E // \left[\dfrac{R_S // R_B + h_{ie}}{h_{fe}+1} \right]$

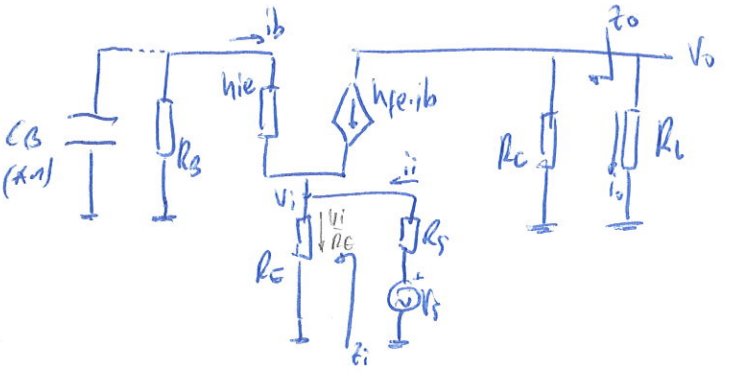


Etapa amplificadora en Base Común

Circuito:



En AC:



- $A_V = \dfrac{V_o}{V_i} = \dfrac{h_{fe} \cdot (R_C // R_L)}{h_{ie} + R_B}$

$V_o = -h_{fe} \cdot i_b \, (R_C // R_L)$

$V_i = V_{RE} = V_{h_{ie}} + V_{RB} = -i_b \left(R_B + h_{ie} \right)$

$A_V > 0$ no hay inversión de fase

$A_V \uparrow$ mediante C_B, $R_B \to 0$.

- $A_i = \dfrac{i_o}{i_i} = \dfrac{h_{fe} \cdot \dfrac{R_C}{R_C + R_L}}{\dfrac{h_{ie} + R_B}{R_E} + h_{fe} + 1} = \dfrac{h_{fe}}{h_{fe}+1} \cdot \dfrac{R_C}{R_C + R_L} \cdot \dfrac{1}{1 + \dfrac{h_{ie} + R_B}{(h_{fe}+1) R_E}}$

$i_o = -h_{fe} \cdot i_b \dfrac{R_C}{R_C + R_L}$

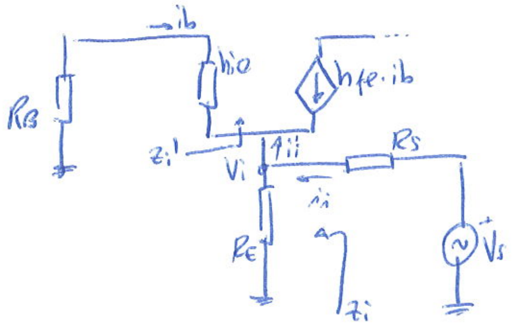
$i_i = i_{RE} - i_{hie} - i_c = \dfrac{V_i}{R_E} - (h_{fe}+1)\, i_b = -\dfrac{i_b (R_B + h_{ie})}{R_E} - (h_{fe}+1) i_b = -i_b \left[\dfrac{R_B + h_{ie}}{R_E} + h_{fe} + 1 \right]$

$\uparrow$ $V_i = -i_b (R_B + h_{ie})$

• $Z_i = Z_i' // R_E$

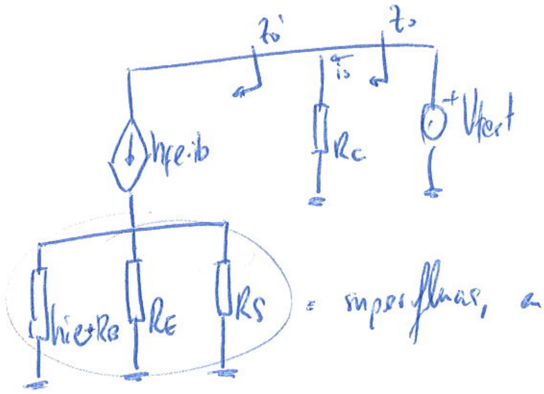
$$Z_i' = \frac{V_i}{I_i} = \frac{V_i}{-(i_b + h_{fe}\, i_b)} = \frac{-i_b\,(R_B + h_{ie})}{-i_b\,(1 + h_{fe})}$$

$$Z_i = R_E // \left[\frac{R_B + h_{ie}}{h_{fe} + 1}\right]$$



• $Z_o = \frac{V_o}{i_o}$?

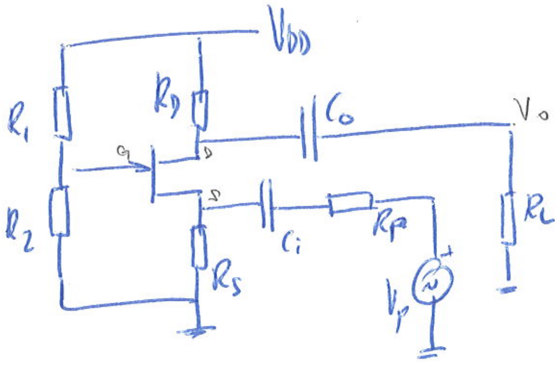
$$Z_o = R_C // Z_o' = R_C$$



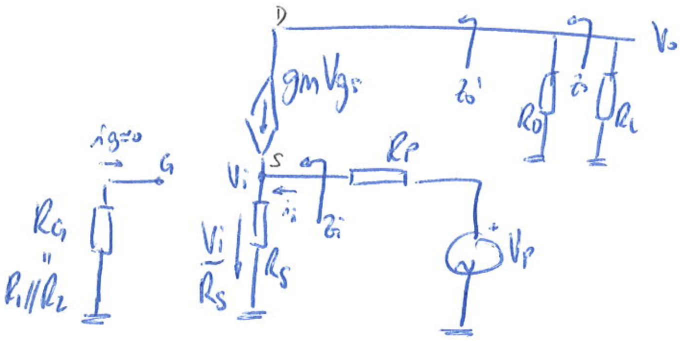
= superfluas, en serie fuente corriente.

Configuraciones con FET

1. Puerta Común.



- En pequeña señal:



* $A_V = \frac{V_o}{V_i} = g_m (R_D // R_L)$

$V_o = -g_m V_{gs} (R_D // R_L)$

$V_i = -V_{gs}$ ⇒ si $i_g \approx 0$, $V_g = 0$ ∴ $V_{gs} = -V_s$

$A_V > 0$ No hay inversión de fase. Si $R_L \downarrow$ ⇒ A_V pequeña.

* $A_i = \frac{i_o}{i_i} = \frac{-g_m \frac{R_D}{R_D + R_L}}{-\left(\frac{1}{R_S} + g_m\right)} = \frac{g_m R_S}{1 + g_m R_S} \cdot \frac{R_D}{R_D + R_L}$

$i_o = -g_m V_{gs} \cdot \frac{R_D}{R_D + R_L}$

$i_i = i_{R_S} - g_m V_{gs}$

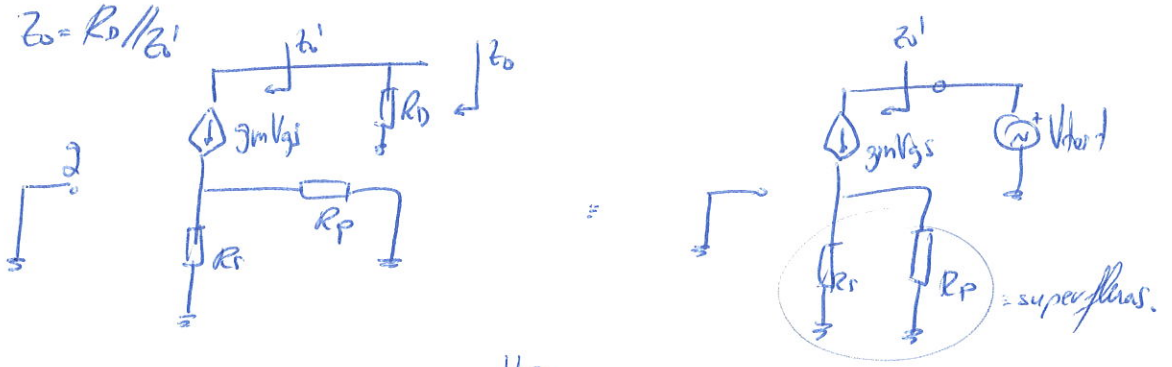
↳ $\frac{V_i}{R_S} = -V_{gs}/R_S$

$\cdot\ z_i = \frac{v_i}{i_i} = \frac{v_i}{\frac{v_i}{R_S} - g_m V_{gs}} = \frac{1}{\frac{1}{R_S} + g_m} = \frac{1}{\frac{1}{R_S} + \frac{1}{\frac{1}{g_m}}} = \underline{R_S // 1/g_m}.$

$V_{gs} = -V_i$

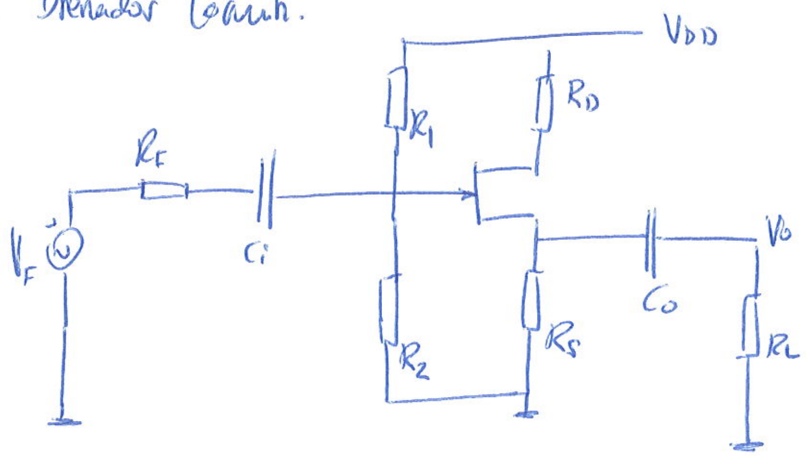
$\cdot\ z_o = R_D$.

$z_o = R_D // z_o'$

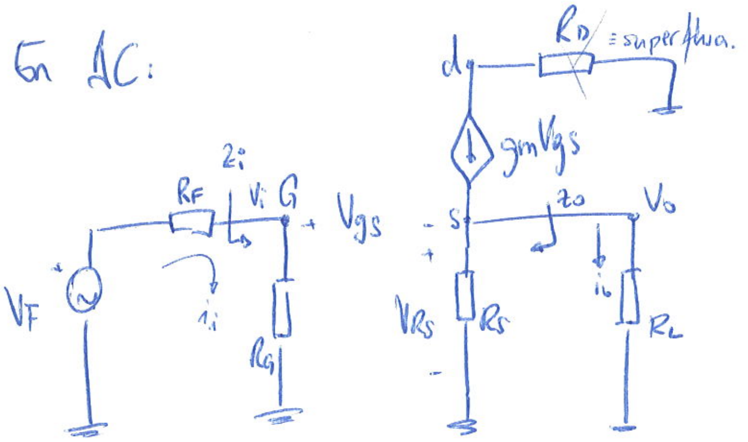


KCL sourceknoop: $g_m V_{gs} = \frac{V_S}{R_S // R_P}$, $V_S = -V_{gs}$ $\Rightarrow V_{gs} = 0 \Rightarrow i_g = 0 \Rightarrow z_o' = \infty$

2. Drenador Común.



En AC:



* $A_v = \frac{V_o}{V_i} = \frac{g_m (R_S \| R_L)}{1 + g_m (R_S \| R_L)}$

$V_o = V_{RS} = g_m V_{gs} (R_S \| R_L)$

$V_i = V_g = V_{gs} + \underset{V_{RS}}{\underset{\shortparallel}{V_o}} = V_{gs} \left[1 + g_m (R_S \| R_L) \right]$

$V_i > V_o \Rightarrow A_v < 1$. Pero $A_v > 0 \Rightarrow$ No hay inversión.

* $A_i = \frac{i_o}{i_i} = \frac{g_m \cdot \frac{R_S}{R_S + R_L}}{\frac{1 + g_m (R_S \| R_L)}{R_G}} = \frac{g_m}{1 + g_m (R_S \| R_L)} \cdot \frac{R_S \cdot R_G}{R_S + R_L}$

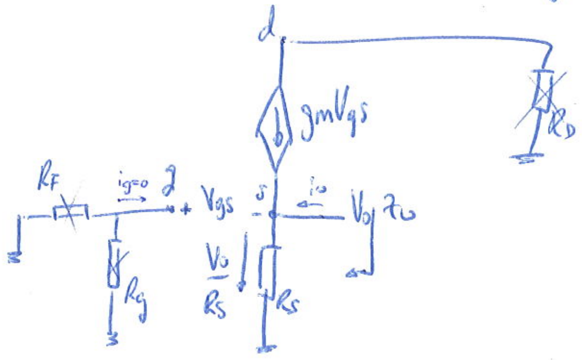
$i_i = i_{RG} = \frac{V_i}{R_G} = \frac{V_{gs} (1 + g_m (R_S \| R_L))}{R_G}$

$i_o = g_m V_{gs} \frac{R_S}{R_S + R_L}$

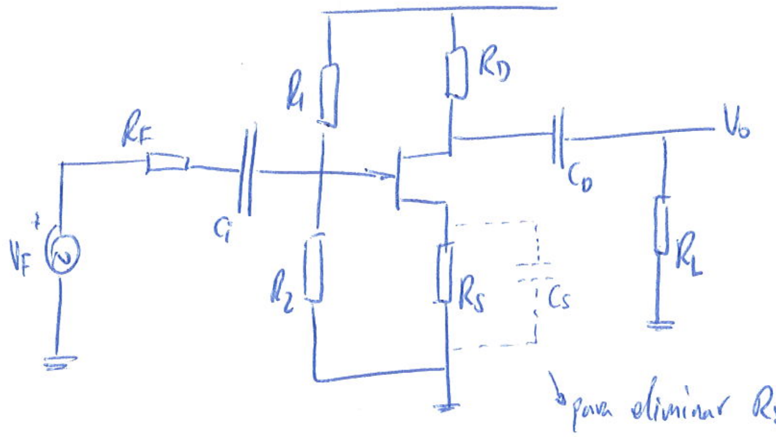
$$\cdot\ Z_i = \frac{V_i}{i_i} = \frac{V_{gs}\left[1+g_m(R_S \parallel R_L)\right]}{\dfrac{V_{gs}\left[1+g_m(R_S \parallel R_L)\right]}{R_G}} = R_G$$

$$\cdot\ Z_o = \frac{V_o}{i_o} = \frac{V_o}{\dfrac{V_o}{R_S} - g_m V_{gs}} = \frac{1}{\dfrac{1}{R_S} + \dfrac{1}{\dfrac{1}{g_m}}} = R_S \parallel \frac{1}{g_m}$$

$-V_{gs} = V_o$

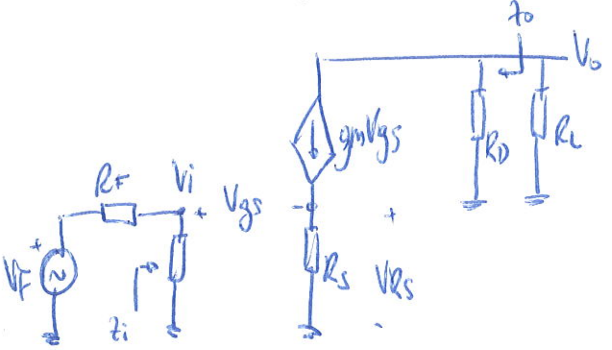


3. Surtidor Común



→ para eliminar R_S en AC.

Circuito en Alterna:



* $A_V = \frac{V_0}{V_i} = -\frac{gm(R_D // R_L)}{1 + gm R_S}$

$V_0 = -gm V_{gs} (R_D // R_L)$

$V_i = V_{gs} + V_{RS} = V_{gs} + gm V_{gs} \cdot R_S$

~~$V_i = V_F \frac{R_G}{R_G + R_F}$~~

NO SIRVE

$A_V < 0$ Hay inversión de fase.

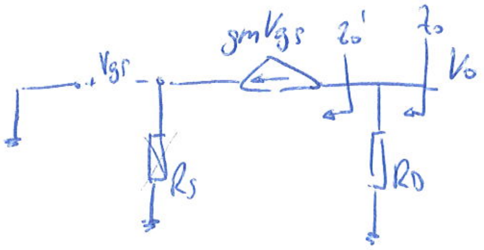
Con $C_S \Rightarrow A_{V_{máx}} = -gm(R_D // R_L)$

* $A_i = \frac{i_o}{i_i} = \frac{-gm V_{gs} \frac{R_D}{R_D + R_L}}{\frac{V_i}{R_G}} = -\frac{gm}{1 + gm R_S} \cdot \frac{R_D R_G}{R_D + R_L}$

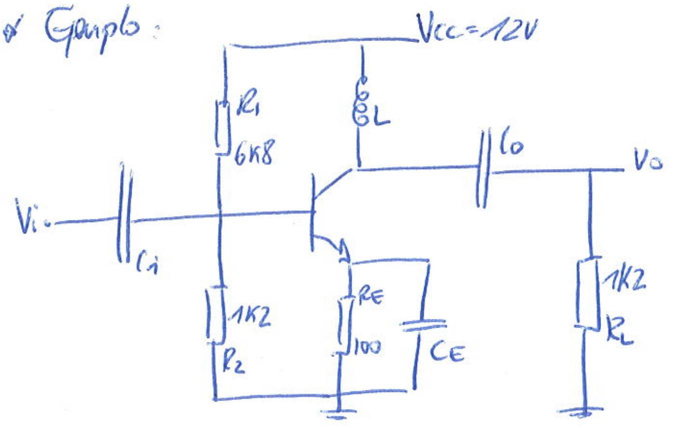
Con $C_S \Rightarrow A_{i_{máx}} = -gm \cdot \frac{R_D R_G}{R_D + R_L}$

* $Z_i = \frac{V_i}{I_i} = \frac{V_i}{\frac{V_i}{R_G}} = R_G$.

* $Z_o = R_D // Z_o' = R_D$.



* Ejemplo:



$h_{fe} = h_{FE} = 100$ $V_{BE_{ACT}} = 0'7V$ $V_{CE_{SAT}} = 1V$

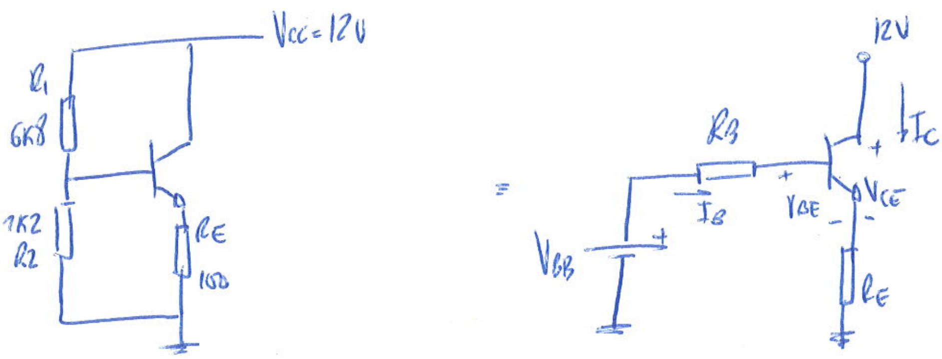
$h_{ie} \simeq \dfrac{V_T}{I_{BQ}}$, $V_T = 25mV$ $h_{oe} = 50\mu S$ $r_{oe} = \dfrac{1}{h_{oe}}$

$L\omega \rightarrow \infty$ $|Z_L| = L\omega \rightarrow \infty$

$C\omega \rightarrow \infty$ $|Z_C| = \dfrac{1}{C\omega} \rightarrow 0$

1, Hallar: AV, Ai, Zi, Zo

Análisis en DC:



$V_{BB} = V_{cc} \cdot \dfrac{R_2}{R_1+R_2} = 1'8V$ ($V_{cc} = 12$, $R_2 = 1K2$, $R_1+R_2 = 8K$)

$R_B = R_1 // R_2 = 1'02K$

$V_{BB} = I_B \cdot R_B + V_{BE} + I_E \cdot R_E = V_{BE} + I_B \left(R_B + (h_{FE}+1) R_E\right)$; $I_B + I_C = I_E$

$I_C = h_{FE} \cdot I_B$

Q

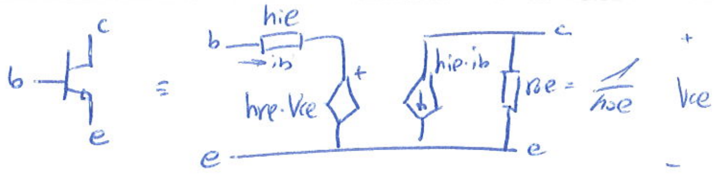
$I_{BQ} = \dfrac{V_{BB} - V_{BEQ}}{R_B + (h_{FE}+1) R_E} = 98'9\mu A$ ($V_{BB} = 1'8V$, $V_{BEQ} = 0'7V$, $R_B = 1'02k$, $h_{FE}+1 = 101$, $R_E = 100$)

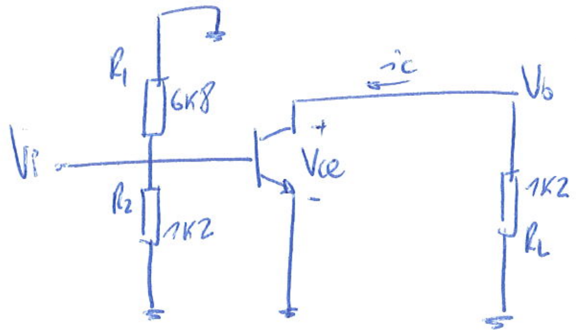
$I_{CQ} = h_{FE} \cdot I_{BQ} = 9'89\ mA$

$V_{CEQ} = V_{CC} - I_{EQ} \cdot R_E = 11\ V$ ($V_{CC} = 12V$, $I_{EQ} = 9'89m$, $R_E = 100$)

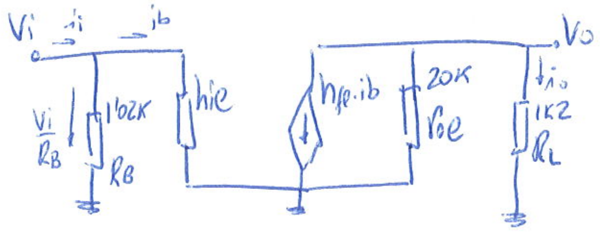
$= V_{CC} = V_{CE} + I_E R_E$; $I_E = I_C$

Análisis en AC





=



RCDS: $V_{ce} = -i_c \cdot R_L \rightarrow i_c = -\frac{V_{ce}}{R_L}$; pend $= -\frac{1}{R_L}$

$$h_{ie} = \frac{V_T}{I_{BQ}} = 252'78\,\Omega \qquad (V_T = 25\,mV;\; I_{BQ} = 98'9\,\mu A)$$

$$r_{oe} = \frac{1}{h_{oe}} = 20\,K\Omega \qquad \left(h_{oe} = \frac{1}{50\,\mu S}\right)$$

$$-\; A_V = \frac{V_o}{V_i} = -\frac{h_{fe}\,(r_{oe} /\!/ R_L)}{h_{ie}} = \underline{-447'8}$$

($h_{fe} = 100$; $r_{oe} = 20K$; $R_L = 1'2K$; $r_{oe}/\!/R_L = 1'13K$; $h_{ie} = 252'78$)

$V_i = i_b \cdot h_{ie}$

$V_o = -h_{fe} \cdot i_b\,(r_{oe} /\!/ R_L)$

$$-\; A_I = \frac{i_o}{i_i} = -\frac{h_{fe}\,(r_{oe} /\!/ R_L) \cdot R_B}{(R_B + h_{ie}) \cdot R_L} = -\frac{h_{fe} \cdot r_{oe}}{r_{oe} + R_L} \cdot \frac{R_B}{R_B + h_{ie}} = \underline{-75'6}$$

($h_{fe} = 100$; $r_{oe} = 20K$; $R_L = 1'2K$; $R_B = 1'02K$; $h_{ie} = 252'78$)

$$i_i = \frac{V_i}{R_B} + i_b = i_b\left(\frac{h_{ie}}{R_B} + 1\right) = i_b \cdot \frac{h_{ie} + R_B}{R_B}$$

$$i_o = \frac{V_o}{R_L} = -\frac{h_{fe} \cdot i_b\,(r_{oe} /\!/ R_L)}{R_L} = -\frac{h_{fe} \cdot i_b \cdot r_{oe}}{r_{oe} + R_L}$$

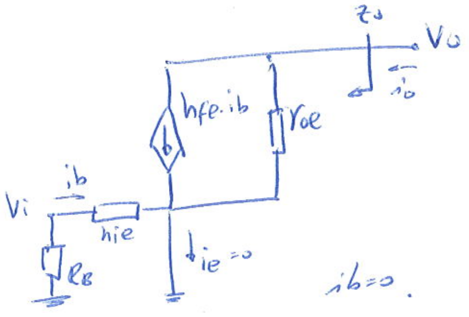
$$-\; Z_i = \frac{V_i}{i_i} = \frac{V_i}{\frac{V_i}{R_B} + \frac{V_i}{h_{ie}}} = (R_B /\!/ h_{ie}) = \underline{202'5\,\Omega}$$

$$i_i = \frac{V_i}{R_B} + i_b = V_i\left(\frac{1}{R_B} + \frac{1}{h_{ie}}\right) = V_i\,\frac{1}{(R_B /\!/ h_{ie})}$$

$$i_b = \frac{V_i}{h_{ie}}$$

$- \; Z_o = \dfrac{V_o}{i_o}$

$Z_o = r_{oe} = \underline{20K\Omega}$.



$i_b = 0$. $i_o = \dfrac{V_o}{r_{oe}}$

2/ MES en Vo?

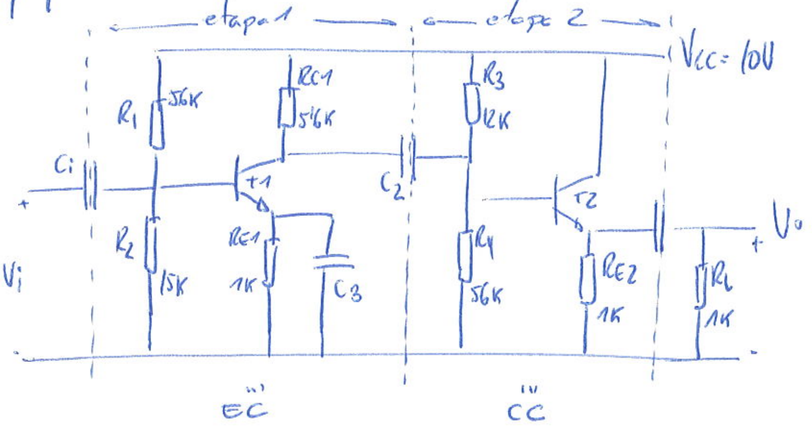
$MES = 2 \times \min\left(\Delta V_{CESAT},\ \Delta V_{CECORTE}\right) = 2 \times \underset{\Delta V_{CESAT}}{\overset{\shortparallel}{10V}} = \underline{20V}.$

$\Delta V_{CESAT} = \underset{11V}{V_{CEQ}} - \underset{1V}{V_{CESAT}} = 10\ V.$

$\Delta V_{CECORTE} = \dfrac{I_{CQ}}{|\text{pend. RCAS}|} = \underset{9'89\,mA}{I_{CQ}} \cdot \overset{1'2K\Omega}{R_L} = 11'86\ V.$

Multietapa

- Ejemplo:



Obs: $A_V \uparrow$ A_i — $A_V \leq 1$ $A_i \uparrow$

$Z_i \uparrow$ $Z_o \uparrow$ — $Z_i \uparrow$ $Z_o \downarrow$

Datos: $T_1 = T_2$

$V_{BE_{ACT}} = 0'7V$

$V_{CE_{SAT}} = 0'5V$

$h_{fe} = h_{FE} = 100$

$h_{ie} = 1k\Omega$

C's ≡ c.c. a frec. trabajo

1/ Q?

2/ MES en Vo?

1/ Q? Análisis en DC

et. 1:

$$I_{BQ1} = \frac{V_{BB1} - V_{BEQ_{ACT}}}{R_{B1} + (h_{FE}+1)R_{E1}} = 12'5\,\mu A$$

con $V_{BB1} = V_{CC} \cdot \frac{R_2}{R_1+R_2}$, $V_{CC} = 10V$, $R_2 = 15K$, $V_{BEQ_{ACT}} = 0'7V$, $R_{B1} = R_1 // R_2 \equiv 56K$, $h_{FE} = 100$, $R_{E1} = 1K$

$$I_{CQ1} = h_{FE} \cdot I_{BQ1} = 1'25\,mA$$

$$V_{CEQ1} = V_{CC} - I_{CQ1}(R_{E1} + R_{C1}) = 1'75V$$

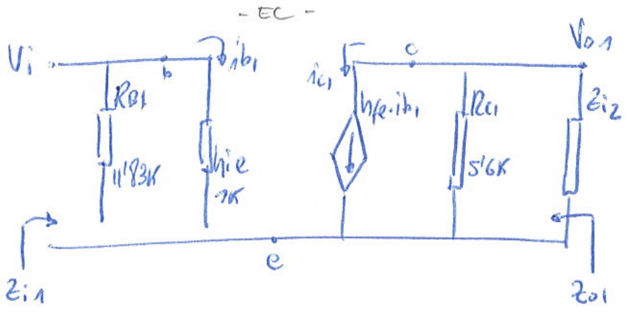
et. 2:

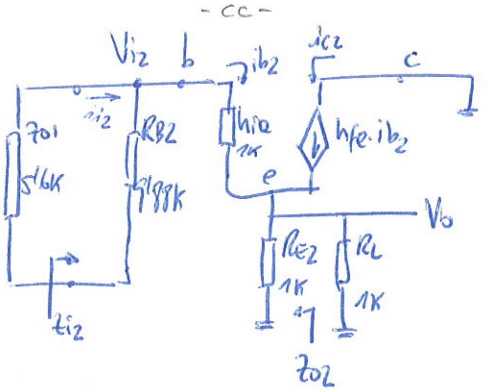
$$I_{BQ2} = \frac{V_{BB2} - V_{BEQ_{ACT}}}{R_{B2} + (h_{FE}+1)R_{E2}} = 68\,\mu A$$

$$I_{CQ2} = h_{FE} \cdot I_{BQ2} = 6'8\,mA$$

$$V_{CEQ2} = V_{CC} - I_{CQ2} \cdot R_{E2} = 3'2V$$

2/ MEP en Vo? Análisis en AC





= CC =

$$Av_2 = \frac{(h_{fe}+1)(R_{E2}//R_L)}{h_{ie}+(h_{fe}+1)(R_{E2}//R_L)} = 0'98 \qquad \Leftarrow \quad Av_2 = \frac{V_o}{V_{i2}}$$

($h_{fe} = 100$, $R_{E2} = 1K$, $R_L = 1K$, $h_{ie} = 1K$, $R_{E2}//R_L = 500\Omega$)

$$Z_{i2} = R_{B2} // \left[h_{ie} + (h_{fe}+1)(R_E//R_L)\right] = 8'29K\Omega \qquad \Leftarrow \quad Z_{i2} = \frac{V_{i2}}{i_{i2}}$$

($R_{B2} = 9'88K$, $h_{ie} = 1K$, $(h_{fe}+1)(R_E//R_L) = 50'5K$)

$$V_o = (R_{E2}//R_L)\cdot i_{b2}(h_{fe}+1)$$

$$V_{i2} = i_{b2}h_{ie} + V_o = i_{b2}\left[h_{ie}+(h_{fe}+1)(R_{E2}//R_L)\right]$$

$$i_{i2} = \frac{V_{i2}}{R_{B2}} + i_{b2} = V_{i2}\left[\frac{1}{R_{B2}} + \frac{1}{h_{ie}+(h_{fe}+1)(R_{E2}//R_L)}\right]$$

= EC =

$$Z_{i1} = R_{B1} // h_{ie} = 0'92K\Omega \qquad \Leftarrow \quad Z_{i1} = \frac{V_i}{i_{i1}}$$

($R_{B1} = 11'83K$, $h_{ie} = 1K$)

; Z_{i1} no depende de Z_{i2} por ser EC.

$$Av_1 = \frac{-h_{fe}(R_{C1}//Z_{i2})}{h_{ie}} = -334'2 \qquad \Leftarrow \quad Av_1 = \frac{V_{o1}}{V_i}$$

($R_{C1} = 5'6K$, $Z_{i2} = 8'29K$)

$$V_{o1} = -h_{fe}\cdot i_{b1}(R_{C1}//Z_{i2})$$

$$V_i = i_{b1}\cdot h_{ie}$$

$$i_{i1} = \frac{V_i}{R_{B1}} + i_{b1} = V_i\left[\frac{1}{R_{B1}} + \frac{1}{h_{ie}}\right]$$

Hemos calculado $\left\{ \begin{array}{l} \overset{(sin\ Z_{o1})}{Z_{i2}} \\ A_{V2} \end{array} \right. \Rightarrow$ hallando $\left. \begin{array}{l} \overset{(con\ Z_{i2})}{Z_{i1}} \\ A_{V1} \end{array} \right\}$ Hemos ido de derecha a izquierda.

Ahora hallaremos $\underset{(sin\ Z_{i2})}{Z_{o1}} \Rightarrow$ para hallar $\underset{(con\ Z_{o1})}{Z_{o2}}$ de izq. a der.

$$Z_{o1} = \frac{V_{o1}}{i_{o1}} = R_{C1} = 5'6\ K\Omega$$

$\llcorner V_i = 0 \Rightarrow i_{b1} = 0$

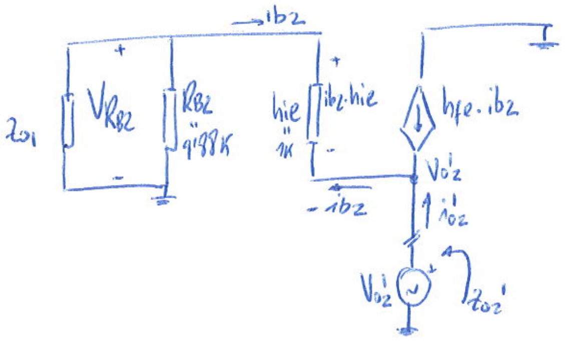
$$V_{o1}(sin\ Z_{i2}) = -h_{fe} \cdot i_{b1} \cdot R_{C1}$$

$$i_{o1} = -h_{fe} \cdot i_{b1}$$

$$Z_{o2} = \frac{V_o}{i_{o2}} = \underset{1K}{R_{E2}} \,//\, \left[\frac{\underset{5'6K}{Z_{o1}} // \underset{9'88K}{R_{B2}} + \underset{1K}{h_{ie}}}{\underset{100}{h_{fe}+1}} \right] = 43'3\ \Omega$$

$$i_{o2} = \frac{V_o}{R_{E2}} - i_{b2} - i_{b2} h_{fe} = \frac{V_o}{R_{E2}} - i_{b2}(h_{fe}+1) = V_o \left[\frac{1}{R_{E2}} + \frac{h_{fe}+1}{Z_{o1}//R_{B2} + h_{ie}} \right]$$

$$i_{b2} = \frac{-V_o}{Z_{o1}//R_{B2} + h_{ie}}$$



$$Z_{o2} = R_{E2} \,//\, Z'_{o2}$$

$$Z'_{o2} = \frac{V'_{o2}}{i'_{o2}} = \frac{Z_{o1}//R_{B2} + h_{ie}}{h_{fe}+1}$$

$$i'_{o2} = -i_{b2}(h_{fe}+1)$$

$$V'_{o2} = -i_{b2} \cdot h_{ie} - i_{b2} \cdot \underset{V_{RB2}}{Z_{o1}//R_{B2}} = -i_{b2}\left[h_{ie} + Z_{o1}//R_{B2} \right]$$

Para el conjunto:

$$Z_i = Z_{i1} = 0'92\ K\Omega$$

$$Z_o = Z_{o2} = 43'3\ \Omega$$

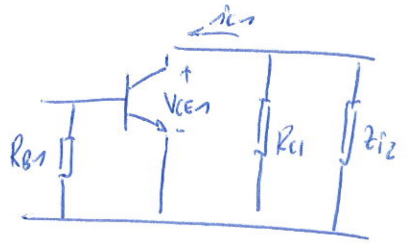
$$A_V = A_{V1} \cdot A_{V2} = -327'7$$

$$A_i = A_V \frac{Z_i}{R_L} = -301'5$$

2/ MES en V_o ⇒ hallar RCAS.

1ª ETAPA

i_{c1}? con Z_{i2}



$$i_{c1} = -\frac{V_{ce1}}{R_{c1} // Z_{i2}} \Rightarrow \text{Pendiente de RCAS} = -\frac{1}{R_{c1} // Z_{i2}}$$

$(V_{ce1} = -i_{c1} (R_{c1} // Z_{i2}))$

MES:

$$\Delta V_{ce1_{SAT}} = \underset{1'75V}{V_{CEQ1}} - \underset{0'5V}{V_{CESAT}} = 1'25V$$

$$\Delta V_{ce1_{CORTE}} = \frac{I_{CQ1}}{|\text{pend. RCAS}|} = \underset{1'25\,mA}{I_{CQ1}} (\underset{5'6K\Omega}{R_{C1}} // \underset{8'29K\Omega}{Z_{i2}}) = 4'18V$$

$$\text{MES de } V_{ce1} = 2 \cdot \text{mínimo} \left(\Delta V_{ce1_{SAT}}, \Delta V_{ce1_{CORTE}} \right) = 2 \cdot 1'25V = \underline{2'5V}.$$

en la 1ª etapa se verifica $\Delta V_o = \Delta V_{ce1}$

2ª ETAPA

$$V_o = V_e - \underset{0}{V_c} = -V_{ce2} = i_{c2} (R_{E2} // R_L)$$

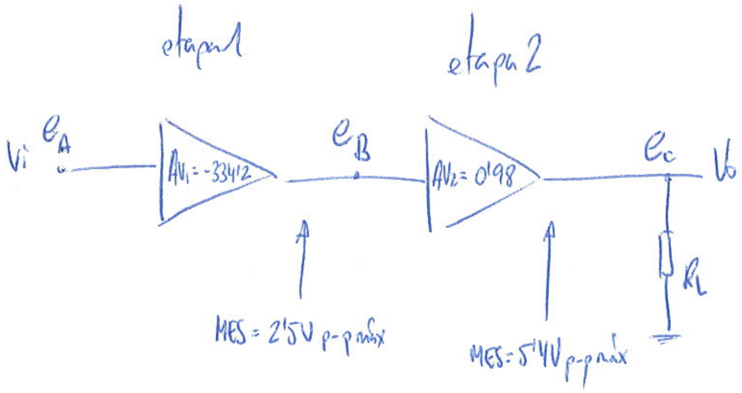
$$i_{c2} = -\frac{V_{CE2}}{(R_{E2} // R_L)} \Rightarrow \text{Pendiente RCAS} = -\frac{1}{(R_{E2} // R_L)}$$

MES:

$$\Delta V_{ce2_{SAT}} = V_{CEQ} - V_{CESAT} = 3'2 - 0'5 = 2'7V$$

$$\Delta V_{ce2_{CORTE}} = \frac{I_{CQ2}}{|\text{pend. RCAS}|} = I_{CQ2} (R_{E2} // R_L) = 3'4V$$

$$MES = 2 \cdot \min \left(\Delta V_{ce2_{SAT}}, \Delta V_{ce2_{CORTE}} \right) = 2 \cdot 2'7V = \underline{5'4V}.$$



$16'49\,mV_{p\text{-}p\,max} \xleftarrow{5'51/334'2} 5'51\,V_{p\text{-}p\,máx} \xleftarrow{5'4/0'98} 5'4\,V_{p\text{-}p\,máx}$

$7'48\,mV_{p\text{-}p\,máx} \xleftarrow{2'5/334} 2'5\,V_{p\text{-}p\,max} \xrightarrow{2'5\times 0'98} 2'45\,V_{p\text{-}p\,máx}$ ← etapa limitante, máxima señal permitida en la entrada sin deformación = $7'48\,mV_{p\text{-}p\,máx}$

'seno recortado'

MES en Vo del multietapa ≡ $2'45\,V_{p\text{-}p\,máx}$.

	ENTRADA V_i NODO A	NODO B	SALIDA V_o NODO C	SUPONIENDO OTRA ETAPA (SALIDA V_o')
MAX SEÑAL DE ENTRADA DE LA ET. 1	$\frac{2'5\,V_{p\text{-}p}}{\lvert A_{V1}\rvert} = 7'48\,mV_{p\text{-}p}$	$2'5\,V_{p\text{-}p}$ MES et. 1	$2'5\,V_{p\text{-}p}\cdot\lvert A_{V2}\rvert = 2'45\,V_{p\text{-}p}$	$2'5\,V_{p\text{-}p}\cdot\lvert A_{V2}\rvert\cdot\lvert A_{V3}\rvert$
ITEM ET. 2	$\frac{5'4\,V_{p\text{-}p}}{\lvert A_{V2}\rvert\cdot\lvert A_{V1}\rvert} = 16'49\,mV_{p\text{-}p}$	$\frac{5'4\,V_{p\text{-}p}}{\lvert A_{V2}\rvert} = 5'51\,V_{p\text{-}p}$	$5'4\,V_{p\text{-}p}$ MES et. 2	$5'4\,V_{p\text{-}p}\cdot\lvert A_{V3}\rvert$
ITEM ET. 3	$\frac{\text{MES et. 3}}{\lvert A_{V3}\rvert\cdot\lvert A_{V2}\rvert\cdot\lvert A_{V1}\rvert}$	$\frac{\text{MES et. 3}}{\lvert A_{V3}\rvert\cdot\lvert A_{V2}\rvert}$	$\frac{\text{MES et. 3}}{\lvert A_{V3}\rvert}$	MES et. 3

Ejercicio: (continuación del Multietapa)

Mejorar la MES en V_o: modificará: R_3, R_4 y R_{C1}

a) Asegurar MES en V_{o2} sea óptima: Modificar R_3 y R_4 para obtener MES óptima en la 2ª etapa.

$$\Delta V_{CE2_{SAT}} = \Delta V_{CE2_{CORTE}} \Rightarrow \underset{?}{V_{CEQ2}} - \underset{0'5V}{V_{CESAT}} = \underset{?}{I_{CQ2}} \left(\underset{0'5k\Omega}{R_{E2}//R_L} \right)$$

↑

Para mejorar MES en V_{o2} (2ª etapa) exigimos márgenes idénticos

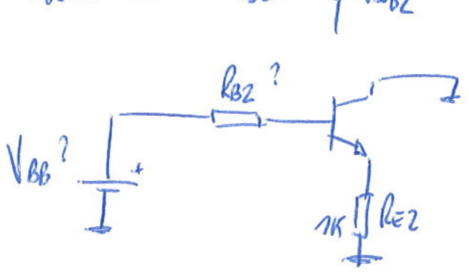
Respetamos RCCS: $\underset{10V}{V_{CC}} = \underset{?}{V_{CEQ2}} + \underset{?}{I_{CQ2}} \underset{1k}{R_{E2}}$

Resolviendo las 2 ecuaciones: Q: $V_{CEQ2} = 3'67V$, $I_{CQ2} = 6'33mA$

$$\underset{\text{en } V_{o2}}{MES} = 2 \cdot \underset{\Delta V_{CE_{CORTE}}}{\Delta V_{CE_{SAT}}} = 2 \cdot \left(\overset{V_{CEQ2}}{3'67} - \underset{V_{CESAT}}{0'5} \right) = 2 \cdot 3'17V = 6'34V$$ antes era de 5'4V.

fijamos directamente Q por no poder tocar R_{E2}

hallemos V_{BB2} y R_{B2} $\Rightarrow$ $R_3 = ?$, $R_4 = ?$



$I_{BQ2} = \frac{I_{CQ2}}{h_{FE}}$ $\qquad I_{CQ2}$

1. $V_{BB2} = I_{BQ2} \cdot R_{B2} + V_{BEQ2} + I_{EQ2} \cdot R_{E2}$

$I_{BQ2} = \frac{6'33mA}{100}$, $V_{BEQ2} = 0'7V$, $I_{EQ2} = 6'33mA$, $R_{E2} = 1K$

2. Condición estabilidad del Q:

$R_{B2} \ll h_{FE} \cdot R_{E2}$ $\qquad$ tomando $R_{B2} = \frac{h_{FE} \cdot R_{E2}}{10} = 10K\Omega$ ($h_{FE} = 100$, $R_{E2} = 1K$)

en 1. $V_{BB2} = 7'67V$

A partir de $\begin{Bmatrix} V_{BB2} \\ R_{B2} \end{Bmatrix}$ hallamos $\begin{Bmatrix} R_3 \\ R_4 \end{Bmatrix}$

$V_{BB2} = V_{CC} \frac{R_4}{R_3 + R_4}$

$R_{B2} = R_3 // R_4$

$R_3 = 15K\Omega$

$R_4 = 43K\Omega$

b) Hallar R_{C1} que permita MES máxima en V_0

Para hallar R_{C1} que asegure MES V_0 global sea máxima, debemos asegurar que la salida de la primera etapa no es la limitante (debemos evitar que la 1ª etapa recorte, para maximizar la amplitud en V_{02}).

$$\text{MES de } V_{01} > \text{MES de } V_{i2} = \frac{\text{MES de } V_{02}}{|A_{V2}|} = 2 \cdot 3'23V$$

MES de V_{01} debido a et. 1; MES de V_{i2} ($= V_{01}$) debido a et. 2; MES de $V_{02} = 2 \cdot 3'17V$; $|A_{V2}| = 0'98$

→ A_{V2} no hay que recalcularla pues no depende de R_3 y R_4.

Análisis etapa 1: (Para hallar R_{C1})

- Debemos hallar Z_{i2} (es R_L de la etapa 1)

$$Z_{i2} = \underbrace{R_1 // R_2}_{R_{B1}} // \left[h_{ie} + (h_{fe}+1)(R_{E2} // R_L) \right] = 8'37\,K \quad \leftarrow \text{Ya visto antes}$$

- ¿Q etapa 1?

I_{BQ1}, I_{CQ2} no dependen de R_{C1}, y tampoco de R_3, R_4, el resto está igual que en el ejemplo anterior:

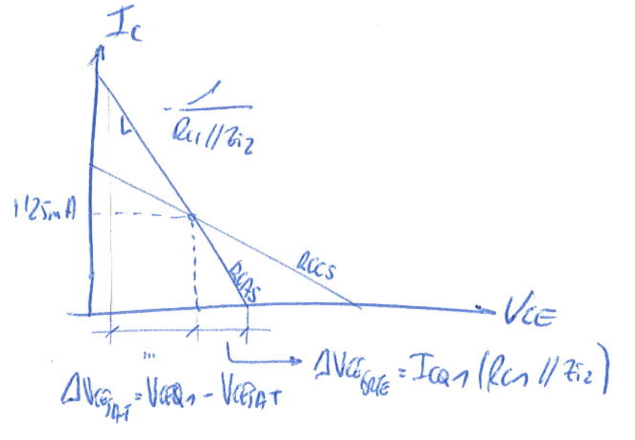
$I_{BQ1} = 12'5\,\mu A \qquad I_{CQ1} = 1'25\,mA$

V_{CEQ1} sí depende de R_{C1}: $\quad V_{CEQ1} = V_{CC} - I_{CQ1}(R_{C1} + R_{E1}) = 8'74V - 1'25mA \cdot R_{C1}$

- RCAS et. 1: sigue siendo $\quad i_{c1} = \dfrac{-V_{ce1}}{R_{C1} // Z_{i2}}$

- Análisis de márgenes, sigue valiendo $\Delta V_{o1} = \Delta V_{ce1}$

por lo tanto ponemos los 2 márgenes directamente en I_C / V_{CE}:



Podríamos exigir $\Delta V_{CE_{CORTE}} = \Delta V_{CE_{SAT}}$

$2 \cdot 3'23\,V$

Pero nos basta con
$$\begin{cases} \Delta V_{CE_{SAT}} \geq \dfrac{MES\ de\ V_{i2}}{2} \\ \Delta V_{CE_{CORTE}} \geq \dfrac{MES\ de\ V_{i2}}{2} \end{cases}$$

→ No es necesario que los 2 márgenes sean iguales

Máxima tensión que soporta la 2ª et. sin llegar a distorsión.

o sea:
$$\begin{cases} \Delta V_{CESAT} = V_{CEQ} - V_{CESAT} = 8'74 - 1'25\,mA \cdot R_{C1} - 0'5 \geq 3'23 \\ \Delta V_{CE_{CORTE}} = I_{CQ}\left(R_{C1} // Z_{i2}\right) = 1'25\,mA\left(R_{C1} // 9'37\,K\Omega\right) \geq 3'23 \end{cases}$$

$$\Rightarrow \begin{cases} R_{C1} \leq 4\,K\Omega \\ R_{C1} \geq 3'74\,K\Omega \end{cases} \Rightarrow \underline{R_{C1} = 3'9\,K\Omega}$$

Globalmente:

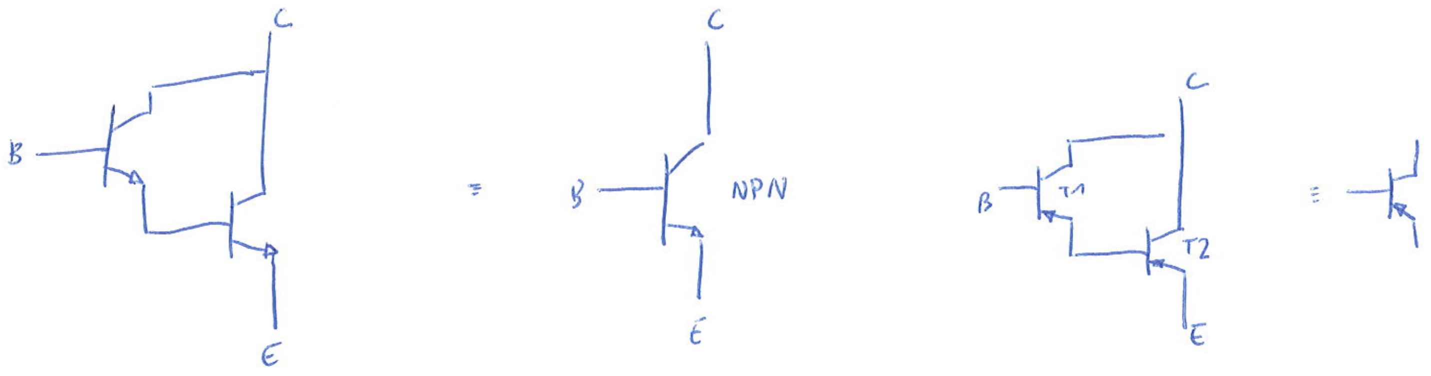
$MES\ V_{o\,global} = MES\ V_{o2}$ debido a etapa 2 $= 2 \cdot 3'17\,V_{p-p}$

Máxima entrada: $\dfrac{MES\ V_{o\,global}}{|A_V|} = \dfrac{2 \cdot 3'17}{266 \cdot 0'98} = 24'4\ mV\ p\text{-}p$

$$A_{V_1} = -\frac{h_{fe}\left(R_{C1} // Z_{i2}\right)}{h_{ie}}$$

Circuitos Integrados

Darlington (Mayor amplificación de corriente)

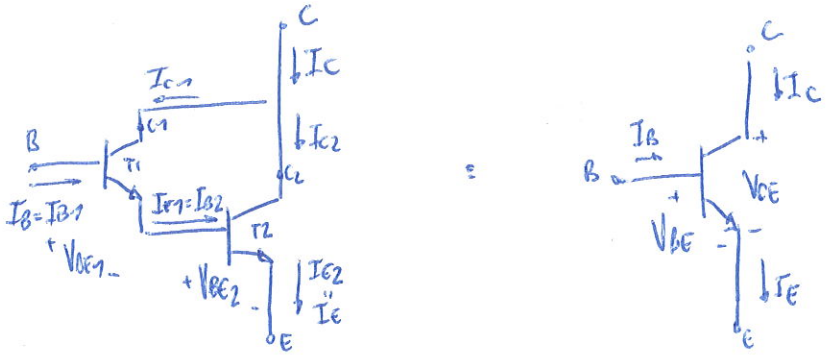


Darlington con NPN

Darlington PNP

1. Análisis DC

NPN:



EQUIVALENTE

Suponiendo activa:

- $V_{BE} = \underset{0'7V}{V_{BE1}} + \underset{0'7V}{V_{BE2}} = \underline{1'4V}$

- h_{FE}

$$I_C = I_{C1} + I_{C2} = I_{B1} \cdot h_{FE1} + I_{B2} \cdot h_{FE2} = I_{B1} h_{FE1} + I_{B1}(h_{FE1}+1) \cdot h_{FE2}$$

$$I_{B2} = I_{E1} = I_{B1}(h_{FE1}+1) \quad ; \quad I_{B1} = I_B$$

$$I_C = I_B \underbrace{\left(h_{FE1} + h_{FE2} + h_{FE1} \cdot h_{FE2}\right)}_{h_{FE}}$$

$$h_{FE} = \frac{I_C}{I_B} = h_{FE1} + h_{FE2} + h_{FE1} \cdot h_{FE2} \simeq \underline{h_{FE1} \cdot h_{FE2}}$$

si $\{h_{FE1}, h_{FE2} \gg 1\}$

- V_{CESAT}

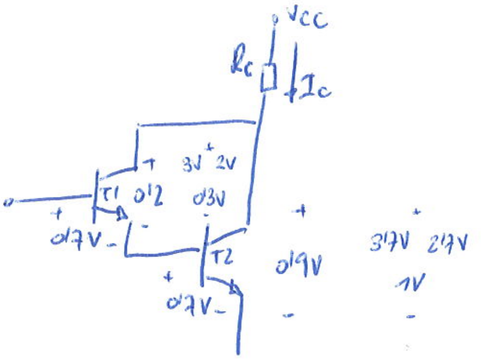
$V_{CE} = V_{CE1} + V_{BE2}$

V_{CE} mínima $\Rightarrow$ V_{CE1} mínima $= 0'2$ si T1 está en SAT.

Si V_{CE1} es mínima, V_{CESAT} también lo es. Si T1 está en SAT V_{CE1} es mínima y vale 0'2V.

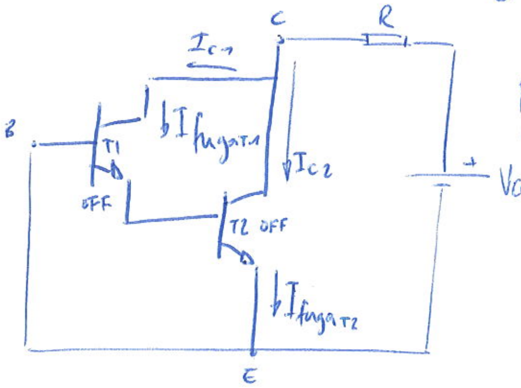
$V_{CESAT} = V_{BE2_{ACT}} + V_{CE1_{SAT}} = 0'7 + 0'2 = \underline{0'9V}$ $\Rightarrow$ T2 nunca estará en SAT.

BJT en SAT $\Rightarrow$ $V_{CE} \simeq 0'2V$.



En V_{CE1} siempre habrán 0'7V menos que en V_{CE} ($= V_{CE2}$). $V_{CE} = V_{CE1} + V_{BE2}$ ($V_{BE2} = 0'7V$)

- Inconvenientes: Corrientes de Fuga. (I_{fuga})

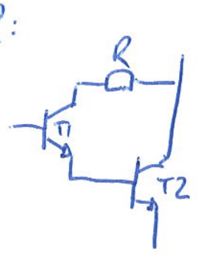


Para polarizarlo correctamente. ($= V_{CC}$)

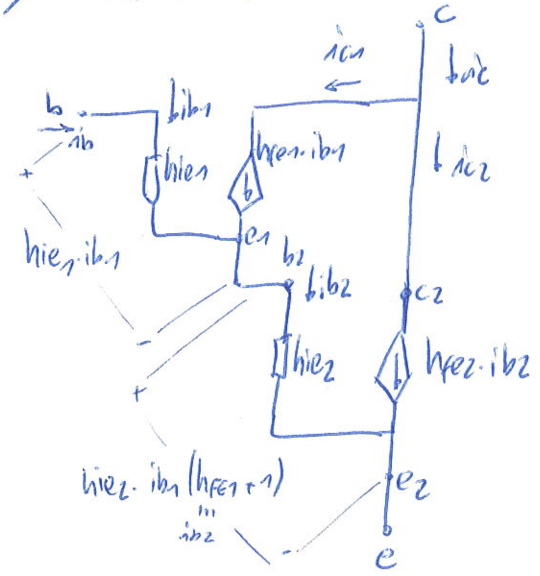
$I_{C1} = I_{C1} + I_{fuga T1} = \beta_1 I_{B1} + (\beta_1 + 1) I_{CBO1}$

$I_{C2} = I_{E1} + I_{fuga T2} = \beta_2 I_{B2} + (\beta_2 + 1) I_{CBO2} = \beta_2 (\beta_1 + 1) I_{B1} + \beta_2 (\beta_1 + 1) I_{CBO1} + (\beta_2 + 1) I_{CBO2}$

Solución: Adición de R:



2/ Análisis AC



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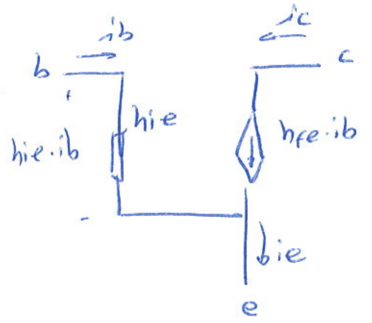


- $h_{fe} = \frac{i_c}{i_b}$

$i_c = h_{fe} \cdot i_b$

$i_c = i_{c1} + i_{c2} = h_{fe1} \cdot i_{b1} + h_{fe2} \cdot i_{b2} = i_b \left(h_{fe1} + h_{fe2} + h_{fe1} \cdot h_{fe2} \right)$

$i_{b2} = i_{e1} = (h_{fe1}+1) i_{b1}$; $i_{b1} = i_b$

$\underline{h_{fe} \simeq h_{fe1} \cdot h_{fe2}}$ si $h_{fe1} \gg 1$, $h_{fe2} \gg 1$.

- $h_{ie} = \left.\frac{V_{be}}{i_b}\right|_{V_{ce}=0} = \frac{h_{ie1} \cdot i_{b1} + h_{ie2}(h_{fe1}+1) \cdot i_{b1}}{i_{b1}} = h_{ie1} + (h_{fe1}+1) h_{ie2} =$

$= h_{ie1} + (h_{fe1}+1) \cdot \frac{h_{ie1}}{(h_{FE1}+1)} = \underline{2 h_{ie1}}$

$h_{fe1} = h_{FE1}$

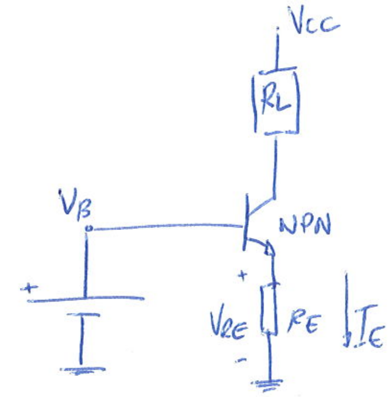
Se vio: $h_{ie} \simeq \frac{V_T}{I_{BQ}}$

en nuestro caso: $h_{ie2} = \frac{V_T}{I_{BQ2}} = \frac{V_T}{I_{BQ1}(h_{FE1}+1)} = \frac{h_{ie1}}{h_{FE1}+1}$

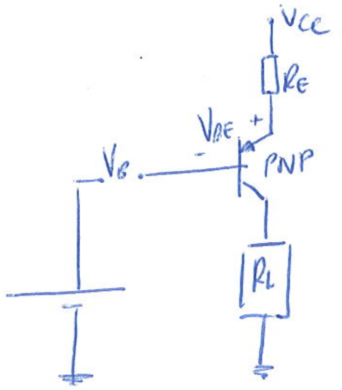
($\frac{V_T}{I_{BQ1}} = h_{ie1}$)

Fuentes de corriente con un BJT

1. Polarización mediante fuente de tensión:

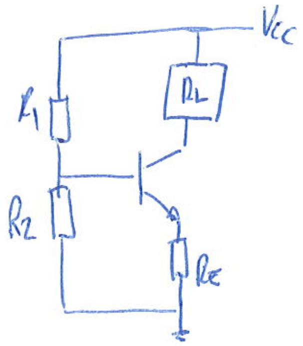


$$I_E = \frac{V_{RE}}{R_E} = \frac{V_B - 0'7}{R_E}$$



$$I_E = \frac{V_{RE}}{R_E} = \frac{V_{CC} - (V_B + 0'7)}{R_E}$$ si está en activa.

2.



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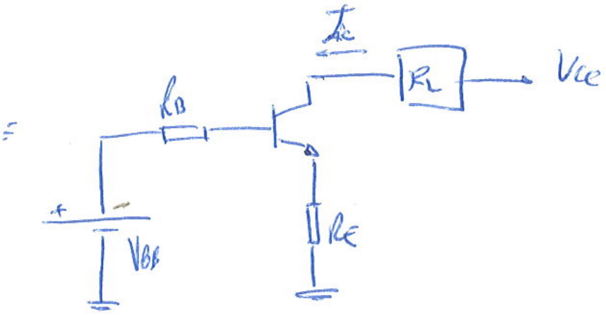
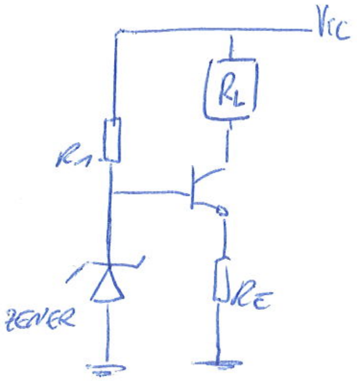


En activa $\Rightarrow$ $I_L = I_C = h_{FE} \cdot I_B = h_{FE} \cdot \dfrac{V_{BB} - V_{BE_{ACT}}}{R_B + (h_{FE}+1)R_E} \simeq$

Diseño: $R_B \ll h_{FE} \cdot R_E$; $\simeq \dfrac{V_{BB} - V_{BE_{ACT}}}{R_E}$

$h_{FE} \gg 1$

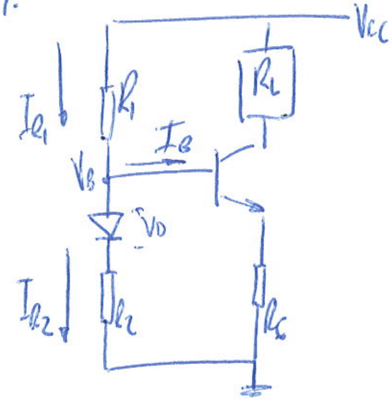
3.



$$I_L = I_C \simeq I_E = \frac{V_Z - V_{BE_{ACT}}}{R_E}$$

↑ Act. $V_Z < V_{CC}$

4.

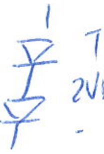
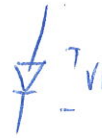


Si $I_B << I_{R1} \Rightarrow I_{R1} \simeq I_{R2} \Rightarrow I_{R1} = I_{R2} = \dfrac{V_{CC} - V_D}{R_1 + R_2}$

Así $V_B = V_D + I_{R2} \cdot R_2 = V_D + \dfrac{V_{CC} - V_D}{R_1 + R_2} R_2 = \dfrac{V_{CC} R_2}{R_1 + R_2} + \dfrac{V_D R_1}{R_1 + R_2}$

$$I_L \simeq I_E = \frac{V_B - V_{BE_{ACT}}}{R_E} = \frac{1}{R_E}\left[\frac{V_{CC} R_1}{R_1 + R_2} + \frac{V_D R_1}{R_1 + R_2} - V_{BE_{ACT}}\right]$$

↑ $I_E = \dfrac{V_{RE}}{R_E}$; $V_{BE_{ACT}} = V_B - V_E$ ($V_E = V_{RE}$)

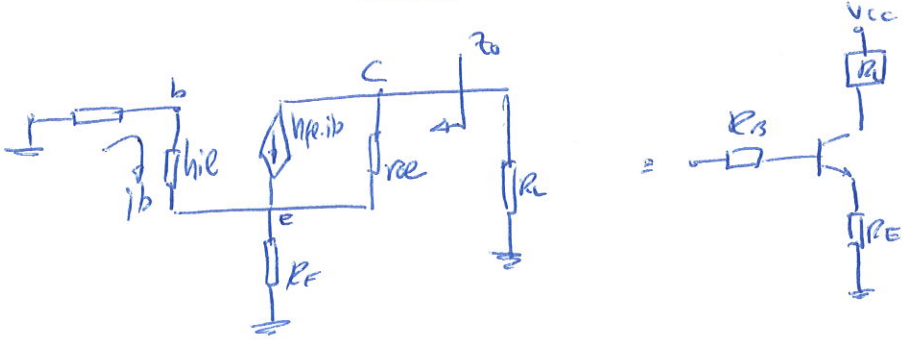
Si $\dfrac{V_D R_1}{R_1 + R_2} = V_{BE}$ ($= V_D$) $\Rightarrow \dfrac{R_1}{R_1 + R_2} \neq 1 \Rightarrow$ Ponemos  $2V_D$ en el lugar de  V_D

y ahora obtendríamos $\dfrac{2 V_D R_1}{R_1 + R_2} = V_D \Rightarrow \dfrac{2 R_1}{R_1 + R_2} = 1 \Rightarrow R_1 = R_2$.

- Impedancia de salida

$$z_o = \frac{(r_{oe} + R_E)(h_{ie} + R_B) + r_{oe} R_E (h_{fe} + 1)}{h_{ie} + R_B + R_E}$$

Proviene de eq. AC:



Habitualmente:

$r_{oe} \gg R_E$

$h_{ie} \sim R_E$

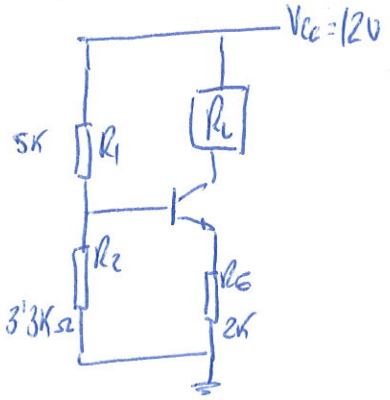
$R_B \sim R_E$

$h_{fe} \gg 1$

$$\Rightarrow z_o \approx \frac{r_{oe} R_E h_{FE}}{h_{ie} + R_B + R_E}$$

$$z_o \simeq r_{oe} \cdot h_{fe} \Rightarrow z_o \gg r_{oe}$$

* Ejemplo:



$h_{FE} = h_{fe} = 100$ $V_{CESAT} = 0'5V$

$h_{ie} = 1K\Omega$ $h_{oe} = 20\mu S$ $V_{CEmáx} = 50V$

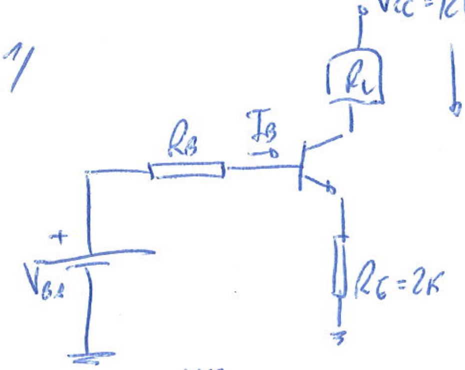
$r_{oe} = 50K\Omega$ $V_{BEACT} = 0'7V$

hallar: 1/ I_L

2/ Margen R_L en la que funciona como fuente de corriente

3/ Z_o.

1/



$I_L = I_{CQ} = h_{FE} \cdot I_{BQ}$

$R_B = 5K // 3'3K = 1'988K$

$V_{BB} = 12 \dfrac{3'3K}{(3'3+5)K} = 4'77V$

$$I_{BQ} = \frac{\overset{4'77}{V_B} - \overset{0'7V}{V_{BEACT}}}{\underset{2K}{R_B} + (\underset{101}{h_{FE}+1})\underset{2K}{R_E}} = 20\mu A \Rightarrow I_L = \underset{100}{h_{FE}} \cdot I_{BQ} = \underline{2mA}.$$

2/ Márgenes de R_L. Funciona correctamente si está en ACT.

$$\underset{V_{CESAT}}{0'5} \leq V_{CE} \leq \underset{V_{CEmáx}}{50V}$$

↑

V_{CE} no puede ser menor de 0'5V porque estaría en SAT.

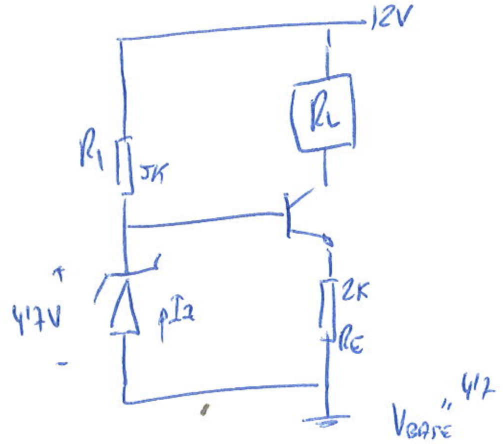
$$V_{CE} = V_{CC} - I_L \cdot R_L - \underset{I_L = 2mA}{I_E} \underset{2K}{R_E} = 8 - \underset{0'002 = 2mA}{I_L} \cdot R_L$$

$$0'5 \leq 8 - 0'002 R_L \leq 50 \Rightarrow \begin{cases} R_L \leq 3'75 K\Omega \\ R_L \geq -21K \end{cases} \Rightarrow \boxed{0 \leq R_L \leq 3'75K\Omega}$$

3/

$$Z_o = \frac{(\underset{50K}{r_{oe}} + \underset{2K}{R_E})(\underset{1K}{h_{ie}} + \underset{2K}{R_B}) + \underset{50K}{r_{oe}} \cdot \underset{2K}{R_E}(\underset{100}{h_{fe}} + 1)}{\underset{1K}{h_{ie}} + \underset{1'998K}{R_B} + \underset{2K}{R_E}} = \underline{2'06\ M\Omega}.$$

* Ejercicio: Substituir R_2 por un zener ideal de 4'7 V, y hallar I_c y Z_o.



- $$I_L \approx I_E = \frac{\underset{4'7}{V_Z} - \underset{0'7}{V_{BEact}}}{\underset{2K}{R_E}} = \underline{2mA} \approx I_c$$

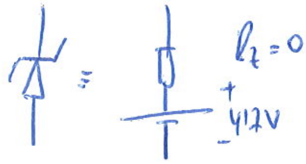
($V_{BASE} = 4'7$)

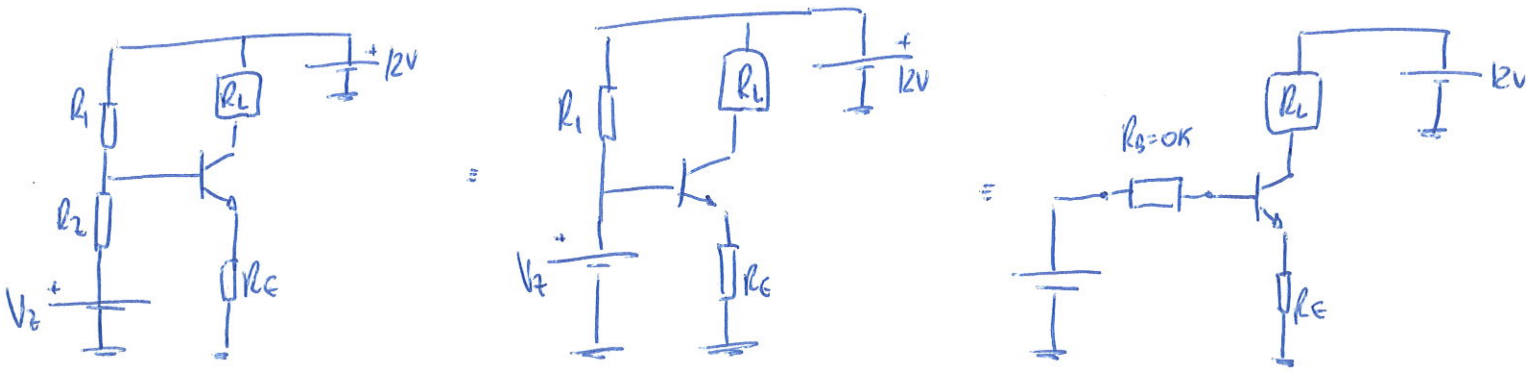
Suponiendo zener real verificamos su corriente:

$$I_Z = I_{R_1} = \frac{12V - 4'7V}{R_1} - \cancel{I_B} = 1'44mA \text{ para un zener no ideal.}$$

despreciable

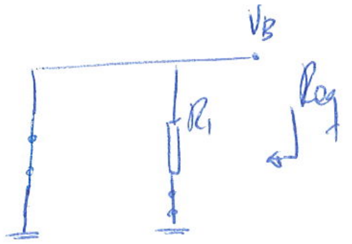
- $Z_o = ?$





$R_B = 0\,\Omega$: R_{eq} ?

curt circuit de fonts de tensió →

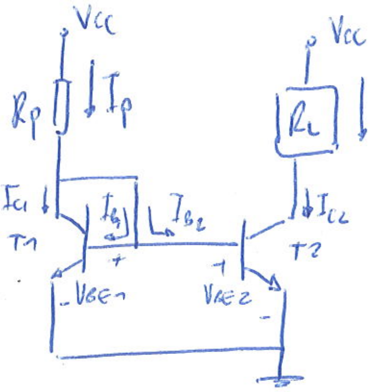


$$Z_o = \frac{(r_{oe} + R_E)(h_{ie} + R_B) + r_{oe} \cdot R_E (h_{fe} + 1)}{h_{ie} + R_E + R_B} = \underline{3'38\ M\Omega}$$

($r_{oe} = 50K$, $R_E = 2K$, $h_{ie} = 1K$, $h_{fe}+1 = 101$)

Espejos de corriente

1.



$\overset{+}{V_{RL}}$ tensiones de Vcc hasta $V_{CE2\,SAT}$ (0'2V)

$$\boxed{I_{C1} \simeq I_{C2}} \Rightarrow I_P \simeq I_L$$

$V_{BE1} = V_{BE2} \Rightarrow I_C = I_{C1} = I_{C2}$

$$\begin{cases} I_{C1} = I_{ES1} \cdot e^{V_{BE1}/V_T} \\ I_{C2} = I_{ES2} \cdot e^{V_{BE2}/V_T} \end{cases}$$

pues $T1 \equiv T2$

como: $I_{B1} = \dfrac{I_{C1}}{h_{FE1}}$ = ↕ son iguales

$I_{B2} = \dfrac{I_{C2}}{h_{FE2}}$.

$$I_P = I_{C1} + I_{B1} + I_{B2} = I_C + \frac{I_C}{h_{FE}} + \frac{I_C}{h_{FE}} = I_C\left(1 + \frac{2}{h_{FE}}\right)$$

$$I_B = \frac{I_C}{h_{FE}}$$

$$\boxed{I_L = \frac{I_P}{1 + \frac{2}{h_{FE}}}}$$

⇐ ACT en ambos.

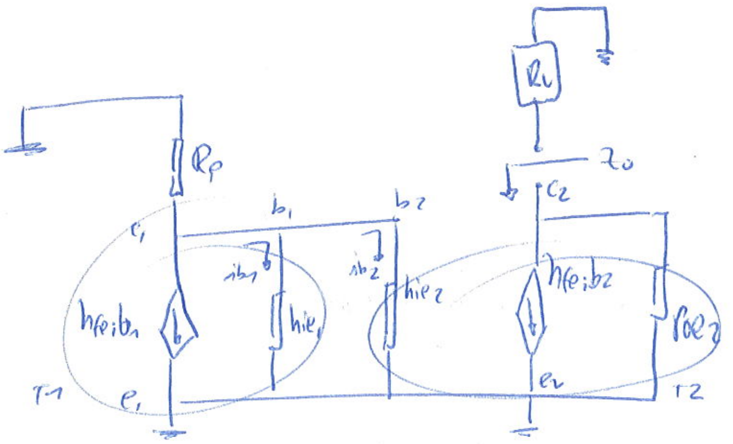
$V_{BE1} = V_{BE2} = V_{BE}$

$$I_P = \frac{V_{RP}}{R_P} = \frac{V_{CC} - V_{BE\,ACT}}{R_P}$$

($V_{BE\,ACT} \simeq 0'7V$)

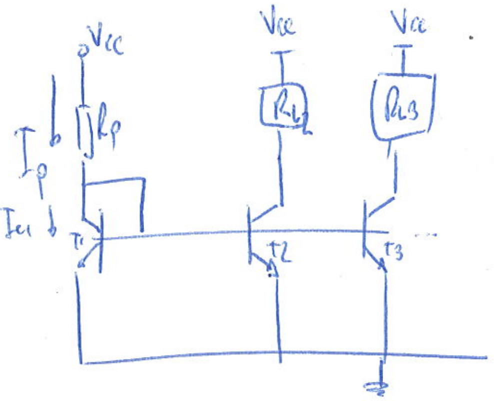
T1 siempre activa pues $V_{CE} = V_{BE} \simeq 0'7V$

- Impedancia de salida



$Z_0 = r_{oe_2}$

- facilidad de extensión



$V_{BE_1} = V_{BE_2} = V_{BE_3} = \dots$

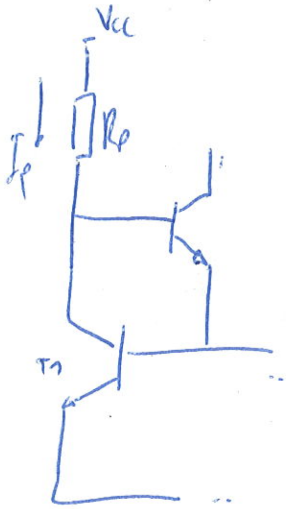
$I_{C_1} = I_{C_2} = \dots$

$I_P = I_{C_1} + \underbrace{I_{B_1} + I_{B_2} + \dots}_{h_{FE} \to n I_B = n \frac{I_C}{h_{FE}}}$

$$I_{C_1} \simeq I_C = I_L = \frac{I_P}{1 + \frac{n}{h_{FE}}}$$

si n grande $I_L \neq I_P$

I_L será $< I_P$

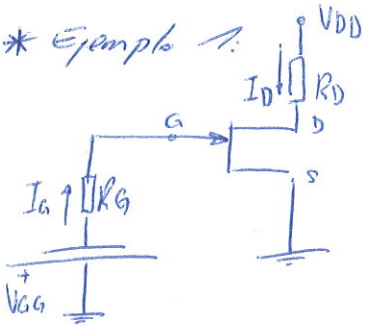


= Solución

Ahora: $$I_L = I_{C_1} = \frac{I_P}{1 + \frac{n}{h_{FE}(h_{FE_a} + 1)}}$$

↑ Transistor acoplado.

* Ejemplo 1:



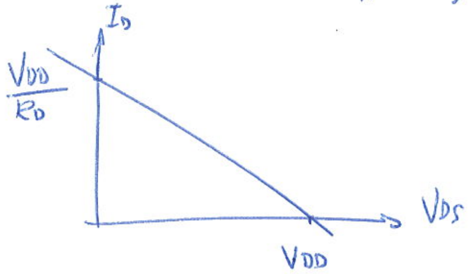
$R_D = 0 \Rightarrow$ se separa la malla de entrada de la salida.

1. KVL1 en malla GS: $-V_{GG} = R_G \cdot I_G + V_{GS} \Rightarrow \boxed{V_{GS} = -V_{GG}}$

   $I_G = 0$

   $I_G \cdot R_G << V_{GS}$

2. KVL2 malla DS: $V_{DD} = I_D \cdot R_D + V_{DS} \rightarrow I_D = \dfrac{V_{DD} - V_{DS}}{R_D}$ Recta de carga en la Salida. (RCCS)



3. Aplicar características de JFET N:

   - Corte? : no ; $V_{GS} < 0$ correcto. $V_{DS} < 0$ correcta.
     $> V_p$
   - Saturación
   - Ω

   } Escogemos SAT, y luego comprobamos.

4. $I_D = I_{DSS} \underbrace{\left(1 - \dfrac{-V_{GG}}{V_p}\right)^2}_{<1} = I_{DQ} < I_{DSS}$

   $I_{DQ} = \dfrac{V_{DD} - V_{DS}}{R_D}$

   $\Bigg\}\ I_{DSS}\left(1 - \dfrac{-V_{GG}}{V_p}\right)^2 = \dfrac{V_{DD} - V_{DS}}{R_D} \overset{S.}{\Rightarrow} V_{DS} = \ldots$

5. $I_{DQ} \Rightarrow$ hallamos $V_{DSQ} \underset{KVL2}{=} V_{DD} - I_{DQ} \cdot R_D$

6. Comprobar si está en SAT.

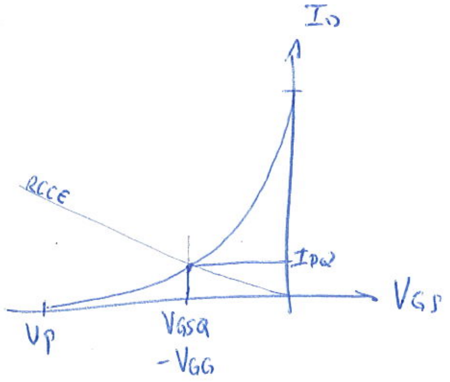
   JFET $N_{SAT} \Leftrightarrow V_{DS} \overset{?}{\geq} V_{GS} - V_p$

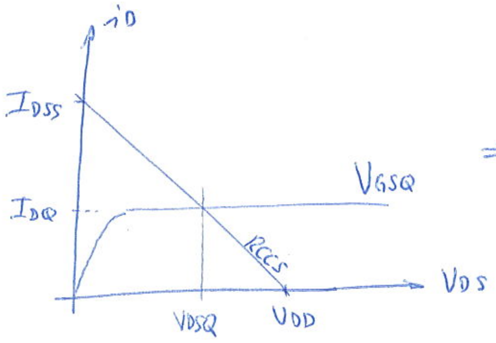
   $V_{GS} = -V_{GG}$

7. En caso de no cumplirse el (6) estaríamos en SZ ⟹
⟹ se debería repetir el punto (4) con:

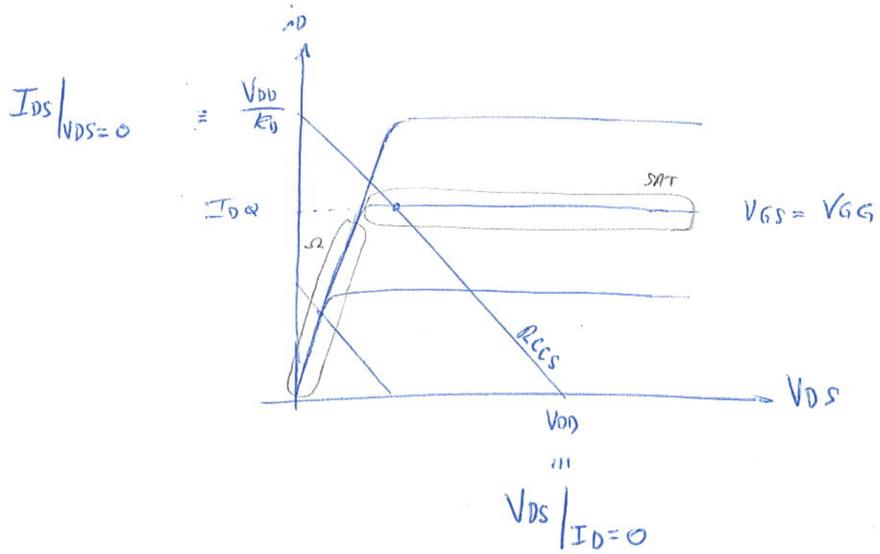
$$r_{DS} = \frac{1}{G_0\left[1 - \sqrt{\frac{V_{GS}}{V_P}}\right]}$$ nos relaciona $$I_{DQ} = \frac{V_{DSQ}}{r_{DS}}$$

8. Curvas características:





⟹ se verifica SAT.



RCCS:

- KVL2 en malla DS: $V_{DD} = I_D \cdot R_D + V_{GS}$

1. $V_{DD}\big|_{V_{DS}=0} = I_D \cdot R_D \longrightarrow I_D = \frac{V_{DD}}{R_D}$; $I_{DS}\big|_{V_{DS}=0}$

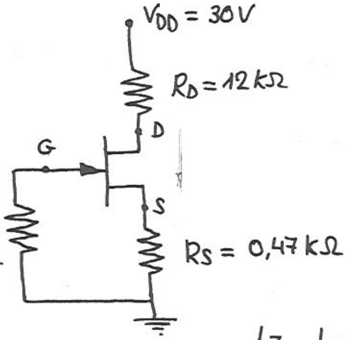
2. $V_{DD}\big|_{I_D=0} = V_{DS}$; $V_{DS}\big|_{I_D=0}$

$\parallel$

$V_{DD} = V_{DS}$

* Ejemplo 2:

- ¿Q?
- ¿Zona de funcionamiento?



→ Vale cuidado, pues V_{R_S} nos proporciona V_{GS}.

$|I_{DSS}| = 3mA$; $|V_p| = 2,4V$

1. Averiguar signos de I_{DSS} y V_p: JFET N $\Rightarrow \begin{cases} I_D > 0 \Rightarrow I_{DSS} > 0 \\ V_{GS} < 0 \Rightarrow V_p < 0 \end{cases}$

2. Análisis de mallas:

KVL1: $R_G I_G = V_{GS} + I_S R_S \Rightarrow I_D = \frac{-V_{GS}}{R_S}$

$R_G I_G = 0$ ⇕ No hay ruptura. Corriente de fuga despreciable.

$I_S = I_D$

Alias "RCCE". Es condición en la curva característica de transferencia.

KVL2: $V_{DD} = I_D R_D + V_{DS} + I_D R_S$

⇕

$I_D = \frac{V_{DD} - V_{DS}}{R_D + R_S}$ RCCS (Lugar geométrico de las tensiones y corrientes aceptadas por V_{DD}, R_D, R_S)

(2 eqs, 3 incogs: V_{GS}, V_{DS}, I_D)

3. Suposición de zona de trabajo: SAT ⇒

$\Rightarrow I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$

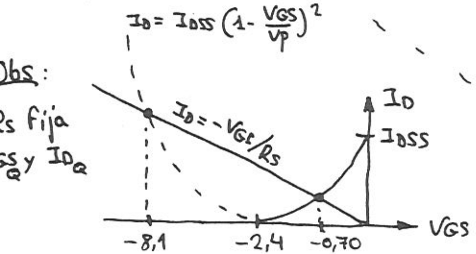
KVL1: $I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2 = \frac{-V_{GS}}{R_S}$

$V_{GS}^2 + 8,885 V_{GS} + 5,76 = 0$

$V_{GS} = $ $-0,704 V$ O.K.; $-8,181 V < V_p = -2,4V$!!!

← Solución sólo matemática.

Obs: Rs fija V_{GSQ} y I_{DQ}



$V_{GS} = -0,704 V \Rightarrow I_D = 1,498 mA$

KVL2: $V_{DS} = V_{DD} - I_D(R_D + R_S) = 11,3 V$

Obs: - R_D ajusta V_{DSQ}.

4. Comprobación de la saturación:

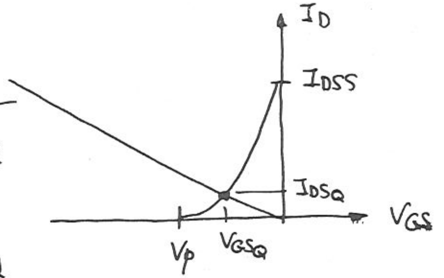
Región de sat ⇔ JFET N: $V_{GS} < 0$; $V_{GS} > V_p$; $V_{DS} \geq V_{GS} - V_p$

Hemos obtenido: $V_{GS} = -0,704 V$ <0, $> -2,4$

$V_{DS} = 11,3 > -0,704 - -2,4$ Sí

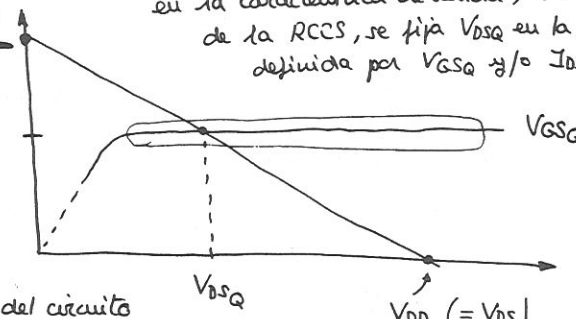
Por lo tanto se verifica SAT.

El análisis gráfico habría comenzado en la característica de transferencia:



$I_D = \frac{-V_{GS}}{R_S}$ Verlo directamente en el circuito.

en la característica de salida, con ayuda de la RCCS, se fija V_{DSQ} en la curva definida por V_{GSQ} y/o I_{DSQ}.

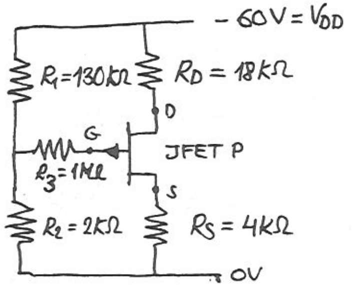


$\frac{V_{DD}}{12k\Omega + 0,47k\Omega} = \left(I_{DS}\Big|_{V_{DS}=0}\right)$

$V_{DD}\ (= V_{DS}\Big|_{I_D=0})$

La RCCS se puede hallar por inspección del circuito en este caso.

* Ejemplo 3: Hallar el punto de reposo y la zona de funcionamiento.



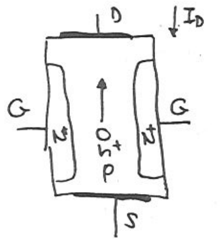
$|I_{DSS}| = 4mA$

$|V_p| = 4V$

Solución:

JFET de canal P ⇒ $V_{GS} \geq 0$ ⇒ $V_p > 0$ $V_p = 4V$

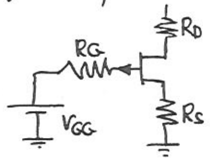
$I_D \leq 0$ ⇒ $I_{DSS} < 0$ $I_{DSS} = -4mA$.



Unión G-canal en inversa ⇒ $V_S < V_G$

h^+ avan al D ⇒ $I_D < 0$

Simplificando por Thevenin:



$V_{GG} = -60 \frac{R_2}{R_2+R_1} = -0{,}91V$

$R_G = R_3 + R_2 // R_1 \simeq 1M\Omega$

1) KVL_1 en malla G-S: $V_{GG} = I_G R_G + V_{GS} + I_S R_S$ (con $I_G = 0$, $I_S = I_D$)

"RCCE": $I_D = \frac{-0{,}91 - V_{GS}}{R_S}$

2) KVL_2 en malla D-S: $V_{DD} = I_D R_D + V_{DS} + I_D R_S$

RCCS: $I_D = \frac{-60 - V_{DS}}{R_D + R_S}$.

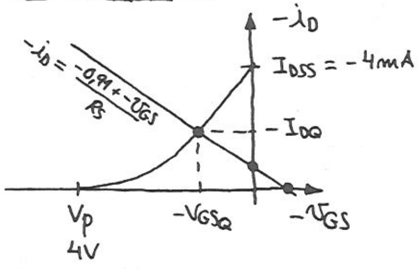
Obs: La ecuación $I_D = \frac{-0{,}91 - V_{GS}}{R_S}$ no es una recta de carga en la entrada: no nos relaciona las resistencias del circuito de entrada ni sus corrientes. Es más una condición de transferencia de la entrada a la salida.

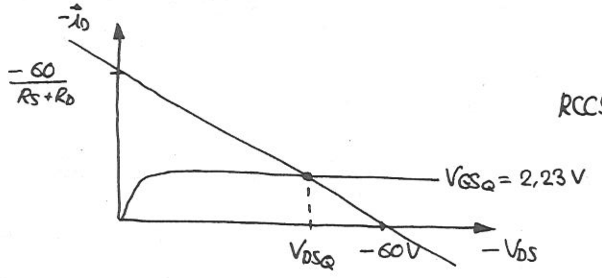
3) Debemos considerar las curvas características del JFETP:

No hay corte en principio pues si $I_D = 0$ ⇒ $\left| \begin{array}{l} V_S = 0 \\ V_G = -0{,}91V \end{array} \right\}$ ⇒ $V_{GS} = -0{,}91V$!! No es V_{GS} de corte.

Suponiendo Saturación: $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$

Solución gráfica:





Solución analítica:

$I_D = \frac{-0{,}91 - V_{GS}}{4K} = -4m\left(1 - \frac{V_{GS}}{4V}\right)^2$

Solución de la cuadrática:

$\left\{ \begin{array}{l} V_{GS} = 6{,}77 > V_p \text{ !!} \\ V_{GSQ} = 2{,}23V \text{ Si} \Rightarrow \end{array} \right.$

$\Rightarrow I_{DQ} = \frac{-0{,}91 - 2{,}23}{4K} = -0{,}785mA$

RCCS: $I_D = -0{,}785m = \frac{-60 - V_{DS…}}{R_D + R_S}$

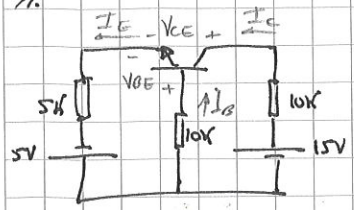
$V_{DSQ} = -42{,}7V$

Comprobación de la saturación: directamente de la gráfica o bien:

sat ⇔ $V_{DS} \leq V_{GS} - V_p$ ✓.

$V_{DS} = -42{,}7$, $V_{GS} = 2{,}3$, $V_p = 4$

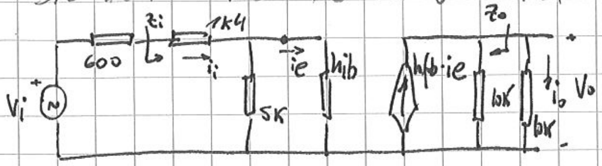
1.



$\alpha = 0'99$

$5V = I_B \cdot 10K + V_{BE} + I_E \cdot 5K$ $\quad I_{BQ} = (1-\alpha) I_{EQ}$ $\quad I_{EQ} = 0'843 mA > 0 \rightarrow ACT ; SAT$

$15 = I_C \cdot 10K + V_{CE} + I_E \cdot 5K - 5V$ $\quad I_{CQ} = \alpha \cdot I_{EQ} = 0'835 mA$ $\quad V_{CEQ} = 7'435 V > 0'2 V \rightarrow$ ACTIVA



$h_{ib} = \frac{V_T}{I_{EQ}} = \frac{25 mV}{0'843 mA} = 29'65 \Omega$ $\quad h_{fb} = 0'99$

$i_e = \frac{5K}{5K + h_{ib}} \cdot i_i \approx i_i$

$i_o = \frac{10K}{10K + 10K} \cdot h_{fb} \cdot i_e = \frac{10}{20} h_{fb} \cdot i_e$

$A_i = \frac{i_o}{i_i} = \frac{10}{20} \cdot h_{fb} = \underline{0'495}$

$V_o = h_{fb} \cdot i_e \cdot (10K \parallel 10K) = h_{fb} \cdot i_e \cdot 5K$

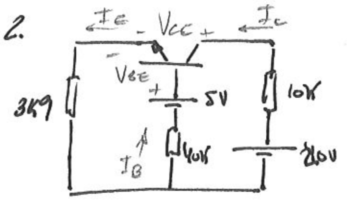
$V_i = [0'6K + 1K4 + (5K \parallel h_{ib})] \cdot i_i$

$A_V = \frac{V_o}{V_i} = \frac{h_{fb} \cdot 5K}{0'6K + 1K4 + (5K \parallel h_{ib})} = \underline{2'44}$

$Z_i = 1K4 + (5K \parallel h_{ib}) = \underline{1'43 K\Omega}$

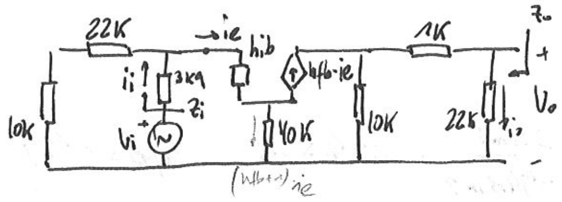
$Z_o = \underline{10K}$

2.



$5 = V_{BE} + I_E \cdot 3K9 + I_B \cdot 40K$ $\quad I_{BQ} = (1-\alpha)\, I_{EQ}$ $\quad I_{EQ} = 1mA > 0 \rightarrow ACT \text{ ó } SAT$

$20 = I_C \cdot 10K + V_{CE} + I_E \cdot 3K9$ $\quad I_{CQ} = \alpha \cdot I_{EQ} = 0'99\,mA$ $\quad V_{CEQ} = 6'2V > 0'2V \rightarrow$ ACTIVA



$h_{ib} = \dfrac{V_T}{I_{EQ}} = 25\,\Omega$

$i_o = \dfrac{10K}{10K+1K+22K} \cdot h_{fb} \cdot i_e = \dfrac{10}{33} \cdot h_{fb} \cdot i_e$

$V_i = 3K9 \cdot i_i + h_{ib} \cdot i_e + (h_{fb}+1) \cdot i_e \cdot 40K$

$Z_i = 3K9 + (Z_i' \,//\, 32K)$

$Z_i' = \dfrac{V_e}{i_e} = h_{ib} + (h_{fb}+1) \cdot 40K \quad \longrightarrow \quad Z_i = 3K9 + [h_{ib} + (h_{fb}+1)\, 40K] \,//\, 32K = \underline{4'32\,K\Omega}$

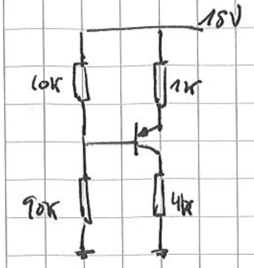
$V_e = (h_{ib} + (h_{fb}+1)\, 40K)\, i_e$

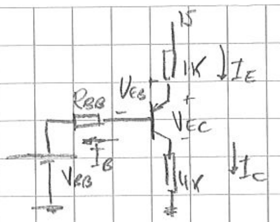
$i_e = \dfrac{3K9}{3K9 + Z_i'} \cdot i_i = i_i$

$A_i = \dfrac{i_o}{i_i} = \dfrac{10}{33} \cdot h_{fb} = \underline{0'3}$

$A_v = A_i \cdot \dfrac{R_L}{Z_i} = \underline{1'53}$

3.





$R_{BB} = 10k // 90K = 9K$

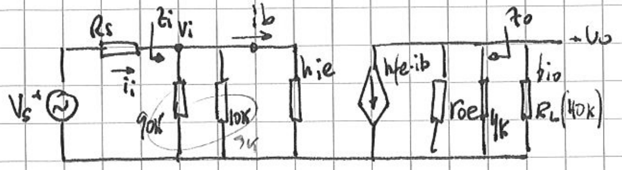
$V_{bb} = \frac{90K}{100K} \cdot 15 = 13'5V$

$15 = I_E \cdot 1K + V_{EB} + I_B \cdot R_{BB} + V_{BB}$

$15 = I_E \cdot 1K + V_{EC} + I_C \cdot 4K$

$I_{EQ} = (\beta+1) I_{BQ}$ (734'27 μA) $I_{BQ} = 7'27\,\mu A > 0 \rightarrow$ ACT ó SAT

$I_{CQ} = \beta \cdot I_{BQ} = 727'27\,\mu A$ $V_{ECQ} = 11'35\,V > 0'2V \rightarrow$ ACTIVA



$hie = 2K\Omega$ $hfe = 100$ $roe = \frac{1}{hoe} = 100K$

$i_b = \frac{9K}{9K + hie} \cdot i_i = \frac{9}{11'1} i_i = 0'81 i_i$

$i_o = -hfe \cdot ib \cdot \frac{roe // 4K}{roe // 4K + R_L} = -8'77\, ib$

$A_i = \frac{i_o}{i_i} = 8'77 \times 0'81 = 7'1$

$V_i = ib \cdot hie$

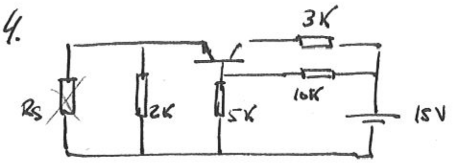
$V_o = -hfe \cdot ib \,(roe // 4K // 40K)$

$A_V = \frac{V_o}{V_i} = -167'1$

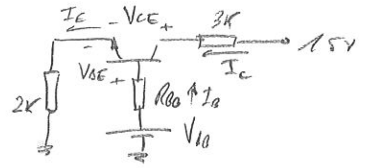
$Z_i = 90K // 10K // hie = 1'7\,K\Omega$

$Z_o = roe // 4K = 3'85\,K\Omega$

4.



$R_S >> 2K$

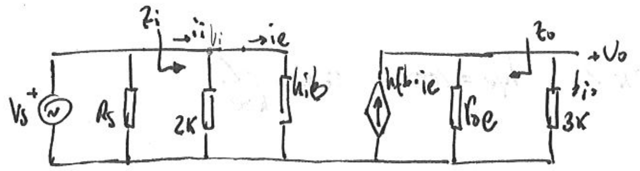


$R_{BB} = 5K // 10K = 3K3$

$V_{BB} = \frac{5K}{15K} \cdot 15 = 5V$

$V_{BB} = I_B \cdot R_{BB} + V_{BE} + I_E \cdot 2K$ $\quad$ $I_{EQ} = (\beta + 1) I_{BQ}$ $\quad$ $I_{BQ} = 21 \mu A > 0 \rightarrow$ ACT ó SAT

$15 = I_C \cdot 3K + V_{CE} + I_E \cdot 2K$ $\quad$ $I_{CQ} = \beta \cdot I_{BQ} = 2'1 mA$ $\quad$ $V_{CEQ} = 4'46 V > 0'2 V \rightarrow$ ACTIVA



$h_{ie} = 1K2$ $\quad$ $h_{fe} = 100$ $\quad$ $h_{oe} \simeq 10^{-4} \Omega^{-1}$

$h_{ib} = 12 \Omega$ $\quad$ $h_{fb} = 0'99$ $\quad$ $r_{ob} = 1M$

$i_e = \frac{2K}{2K + h_{ib}} \cdot i_i = i_i$

$i_o = \frac{r_{oe}}{r_{oe} + 3K} \cdot h_{fb} \cdot i_e = h_{fb} \cdot i_e$

$A_i = \frac{i_o}{i_i} = h_{fb} = \underline{0'99}$

$V_o = h_{fb} \cdot i_e \, (r_{oe} // 3K)$

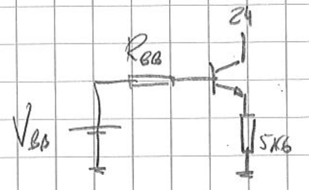
$V_i = i_e \cdot h_{ib}$

$A_v = \frac{V_o}{V_i} = \frac{h_{fb} \overset{3K}{(r_{oe} // 3K)}}{h_{ib}} = \underline{247'5}$

$Z_o = r_{oe} = \underline{1M\Omega}$

$Z_i = 2K // h_{ib} \simeq h_{ib} = \underline{12 \Omega}$

5.



$R_{BB} = 50K // 10K = 8K3$

$V_{BB} = \frac{10K}{60K} \cdot 24 = 4V$

$V_{BB} = I_B \cdot R_{BB} + V_{BE} + I_E \cdot 5K6$

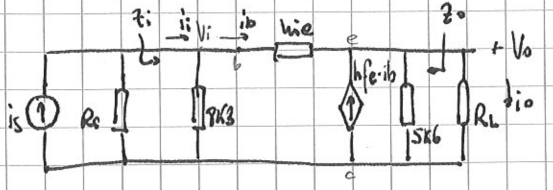
$24 = V_{CE} + I_E \cdot 5K6$

$I_{EQ} = (\beta+1) I_{BQ}$

$I_{EQ} = 0'58 mA$

$I_{EQ} = 5'75 mA > 0 \rightarrow$ ACT ó SAT

$V_{CEQ} = 20'7 V > 0'2V \rightarrow$ <u>ACTIVA</u>



$V_i = hie \cdot ib + (hfe+1) ib (5K6 // R_L)$

$V_o = (hfe+1) ib (5K6 // R_L)$

$A_V = \frac{V_o}{V_i} = \frac{(hfe+1)(5K6 // R_L)}{hie + (hfe+1)(5K6 // R_L)}$

$A_i = A_V \cdot \frac{Z_i}{R_L}$

$Z_i = 8K3 // Z_i'$

$Z_i' = hie + (hfe+1)(5K6 // R_L)$

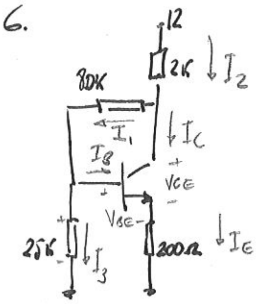
$Z_o = 5K6 // Z_o'$

$Z_o' = \frac{V_P}{i_P} = \frac{hie + (10K // R_S)}{hfe+1}$

$i_P = -(hfe+1) ib$

$V_P = -(hie + 10K // R_S) ib$

6.



$I_2 = I_1 + I_C \quad = I_B + I_C + I_3$

$I_1 = I_B + I_3$

$\beta = 50$

$12 = 2K \cdot I_2 + 80K \cdot I_1 + V_{BE} + I_E \cdot 200$

$12 = 2K \cdot I_2 + V_{CE} + 200 \cdot I_E$

$25K \cdot I_3 = V_{BE} + I_E \cdot 200 \qquad I_3 = \frac{V_{BE} + I_E \cdot 200}{25K} = \frac{V_{BE} + I_{BQ} \cdot (\beta+1) \cdot 200}{25K}$

$I_2 = I_1 + I_C \qquad I_{CQ} = \beta \cdot I_{BQ}$

$$I_2 = I_{BQ} + \frac{V_{BE} + I_{BQ}(\beta+1)200}{25K} + \beta \cdot I_{BQ} = \frac{V_{BE}}{25K} + I_{BQ}(\beta+1)\left(\frac{200}{25K} + 1\right)$$

$$12 = 2K \cdot \left[\frac{V_{BE}}{25K} + I_{BQ}(\beta+1)\left(\frac{200}{25K} + 1\right)\right] + 80K\left[I_{BQ} + \frac{V_{BE} + I_{BQ}(\beta+1)200}{25K}\right] + I_{BQ} \cdot (\beta+1) \cdot 200$$

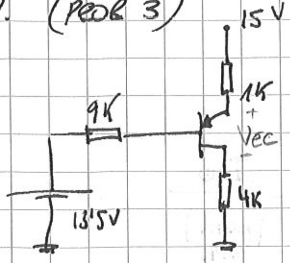
$$12 = V_{BE}\left(\frac{2}{25} + \frac{80}{25}\right) + I_{BQ}(\beta+1)\left[2K\left(\frac{200}{25K} + 1\right) + \frac{80K \cdot 200}{25K} + 80K \cdot 200\right] + 80K \cdot I_{BQ}$$

$\left(\frac{2}{25} + \frac{80}{25}\right) = 3'3$, $(\beta+1) = 51$, $2K\left(\frac{200}{25K}+1\right) = 2K$, $\frac{80K \cdot 200}{25K} = 640$, $80K \cdot 200 = 16M$

$I_{BQ} = \frac{9'3}{816M} = 11'4 \, nA$

Fecha:

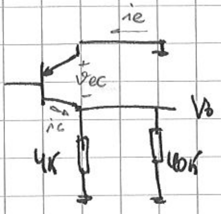
7. (PEOR 3)



BJT PNP en ALTERNA → $I_C \simeq I_E$

$V_{CESAT} = 0'2V$

RCC: $15 = I_C \cdot 1K + V_{EC} + I_C \cdot 4K$ $\qquad I_{CQ} = \frac{15 - V_{ECQ}}{5K}$; $V_{ECQ} = 15 - I_{CQ} \cdot 5K$



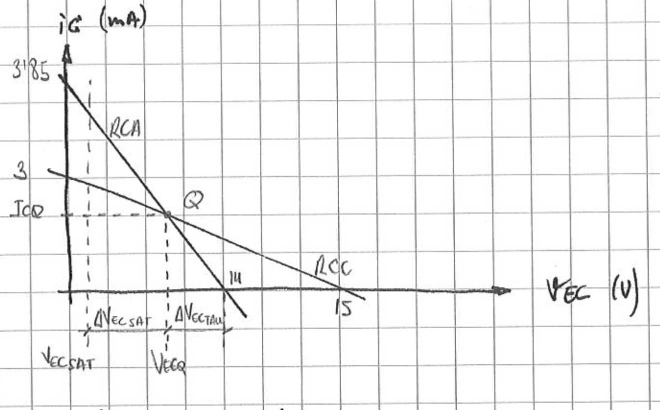
$i_e \simeq i_c$

RCA: $v_{ec} = -i_c \cdot (4K // 40K) = -i_c \cdot 3K6$ $\qquad i_c = -\frac{v_{ec}}{3K6}$

$v_{EC} = V_{ECQ} + v_{ec}$

$i_C = I_{CQ} + i_c \longrightarrow v_{EC} - V_{ECQ} = (I_{CQ} - i_C) \cdot 3K6$ $\qquad I_{CQ} = 727'27 \mu A \quad V_{ECQ} = 11'35V$

$v_{EC} = 14 - i_C \cdot 3K6$ $\qquad$ $i_C = 3'85 - 0'275 \, v_{EC}$ RCA



MÁRGENES DINÁMICOS DE TENSIÓN:

$\Delta V_{ECSAT} = V_{ECQ} - V_{ECSAT} = 11'34 - 0'2 = 11'14 \, V_{pic}$

$\Delta V_{ECTALL} = V_{ECTALL} - V_{ECQ} = 14V - 11'34 = 2'66 \, V_{pic}$

MÁXIMA SEÑAL DE ENTRADA:

$\Delta V_i = \Delta V_o / A_V = 2'66 / 167'1 = 15'9 \, mV_{pic}$

$V_o = -V_{ec}$

$\Delta V_o = 2'66 \, V_{pic}$

- VALORES DE R1 Y R2 PARA MES ÒPTIMA:

· R1 y R2 HACE VARIAR EL PUNTO Q. (I_{CQ}, V_{ECQ})

MES ÒPTIMA: 1/ $\Delta V_{EC_{SAT}} = \Delta V_{EC_{TALL}}$ — $V_{ECQ} - V_{EC_{SAT}} = \frac{I_{CQ}}{|pend_{RCAS}|}$

2/ Q ∈ RCCS, EL NUEVO Q DEBE CUMPLIR: $V_{CEQ} > V_{EC_{SAT}}$ → ACTIVA

NUEVA RCAS: $v_{ce} - V_{ECQ} = (I_{CQ} - i_c) \cdot 3K6$

$$i_c = I_{CQ} - \frac{v_{ec}}{3K6} + \frac{V_{ECQ}}{3K6}$$

1/ $V_{ECQ} - 0'2V = \frac{I_{CQ}}{\left|\frac{1}{3K6}\right|} = I_{CQ} \cdot 3K6$ → $I_{CQ} = \frac{V_{ECQ} - 0'2V}{3K6}$

2/ $V_{CC} = V_{CEQ} + I_{CQ} \cdot 5K$

$$V_{CC} = V_{CEQ} + \frac{V_{ECQ} - 0'2}{3K6} \cdot 5K$$

$$V_{CEQ} = \frac{V_{CC} + \frac{0'2 \cdot 5K}{3K6}}{1 + \frac{5K}{3K6}} = \underline{6'4\ V} > 0'2$$

$I_{CQ} = \underline{1'72\ mA}$ → ACTIVA

VALOR MÁXIM DEL SENYAL SENSE DISTORSIÓ: $(V_o = -V_{EC})$

$$\Delta V_o = \Delta V_{EC_{SAT}} = \Delta V_{EC_{TALL}} = 6'2\ V$$

($\Delta V_{EC_{SAT}} = V_{ECQ} - 0'2$; $\Delta V_{EC_{TALL}} = I_{CQ} \cdot 3K6$)

→ $\Delta V_i = \frac{\Delta V_o}{A_v} = \underline{37'1\ mV_{pic}}$

- CÀLCUL R1 Y R2:

$$15 = 1k \cdot I_{EQ} + V_{EBQ} + R_{BB} \cdot I_{BQ} + V_{BB}$$

$$V_{BB} = 15 \cdot \frac{R_1}{R_1 + R_2}$$

CRITERI $R_B = \frac{1}{10} R_E \cdot (h_{FE} + 1)$

$$R_{BB} = \frac{R_1 R_2}{R_1 + R_2}$$

$R_{BB} = 10'1\ R_E = 10K1$ ($R_E = 1K$)

$V_{BB} = 15 - 1k \cdot I_{EQ} - V_{EBQ} - R_{BB} \cdot I_{BQ} = 12'39\ V$

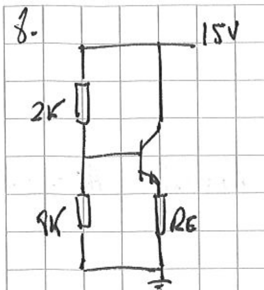
($I_{EQ} = 1'73\ mA$; $V_{EBQ} = 0'7V$; $R_{BB} = 10K1$; $I_{BQ} = 17'2\ \mu A$)

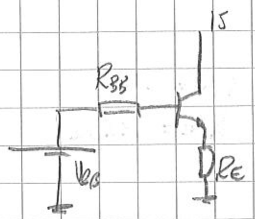
$R_1 = 57'7\ K\Omega$

$R_2 = 12'2\ K\Omega$

Asunto: Fecha: Página: 5

8.





$R_{BB} = 2K // 18K = 1K6\ \Omega$

$V_{BB} = \frac{8K}{10K} \cdot 15 = 12\ V$

$V_{CEQ} = 6'9V \quad \beta = 80$

$15 = V_{CE} + I_E \cdot R_E \qquad I_E = \frac{15 - V_{CE}}{R_E} \qquad I_B = \frac{15 - V_{CE}}{(\beta+1) R_E}$

$V_{BB} = I_B \cdot R_{BB} + V_{BE} + I_E \cdot R_E$

$I_E = (\beta+1) I_B \qquad V_{BB} = \frac{15 - V_{CE}}{(\beta+1) R_E} \cdot R_{BB} + V_{BE} + 15 - V_{CE} \qquad \underline{R_E = 50\ \Omega}$

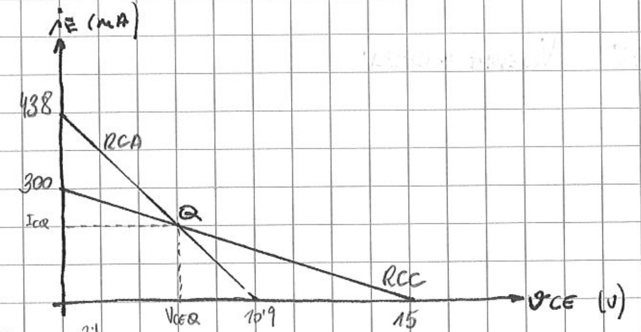
$I_{BQ} = 2mA \quad I_{EQ} = 162\ mA \quad I_{CQ} = 160\ mA \quad V_{CEQ} = 6'9V \quad V_{BEQ} = 0'7\ V$

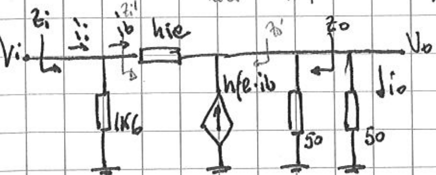
RCC: $15 = V_{CEQ} + I_{EQ} \cdot R_E \qquad I_{EQ} = \frac{15 - V_{CEQ}}{R_E} = 300m - \frac{V_{CEQ}}{50}$

RCA: $v_{ce} = -v_o = -i_e \cdot (R_E // 50) \qquad v_{ce} = -i_e \cdot 25$

$v_{CE} = V_{CEQ} + v_{ce} \qquad v_{ce} = v_{CE} - \overset{6'9V}{V_{CEQ}}$

$i_E = I_{EQ} + i_e \qquad i_E = \frac{15 - V_{CEQ}}{R_{E//50}} - \frac{v_{ce}}{25} \Rightarrow i_E = 438m - \frac{v_{CE}}{25}$





$h_{fe} = 100 \quad h_{ie} = 600\ \Omega$

$V_o = (h_{fe}+1) i_b \cdot (50 // 50) = (h_{fe}+1) i_b \cdot 25$

$V_i = h_{ie} \cdot i_b + (h_{fe}+1) i_b \cdot 25$

$\cdot\ A_v = \frac{V_o}{V_i} = \frac{(h_{fe}+1) 25}{h_{ie} + (h_{fe}+1) 25} = \underline{0'808}$

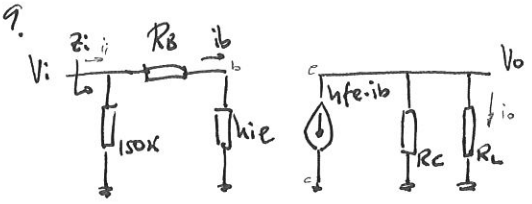
$\cdot\ Z_i = 1K6 // Z_i' = 1K6 // [\overset{3125\ \Omega}{h_{ie} + (h_{fe}+1) \cdot 25}] = \underline{1K}$

$Z_i' = \frac{V_i}{i_b} = h_{ie} + (h_{fe}+1) 25 = 3'125\ K\Omega$

$\cdot\ Z_o = 50 // Z_o' = 50 // \left[\frac{h_{ie}}{h_{fe}+1} \right] = \underline{5'3\ \Omega}$

$Z_o' = \frac{V_p}{i_p} = \frac{h_{ie} \cdot i_b}{(h_{fe}+1) \cdot i_b} = 5'94$

9.



$h_{fe} = 240$

$Z_i = 100\,K\Omega$ $\quad h_{ie} = 2K\Omega$ $\quad A_v = -6$ $\quad A_i = -30$

$Z_i = 150K \,//\, [R_3 + h_{ie}]$ $\qquad 100K = \dfrac{150K \cdot (R_3 + h_{ie})}{150K + R_3 + h_{ie}}$ $\qquad \boxed{R_3 = 298\,K\Omega}$

$V_o = -h_{fe} i_b (R_C // R_L) = -h_{fe} \cdot i_b \cdot \dfrac{R_C R_L}{R_C + R_L}$ $\qquad i_o = \dfrac{V_o}{Z_L}$ $\qquad i_i = \dfrac{V_i}{Z_i}$

$V_i = (h_{ie} + R_3)\, i_b = 300K \cdot i_b$

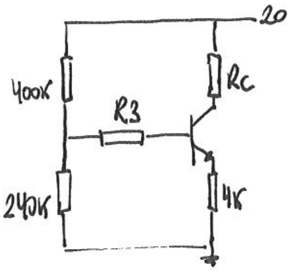
$A_v = \dfrac{V_o}{V_i} = -\dfrac{h_{fe} \cdot (R_C // R_L)}{h_{ie} + R_3}$ $\qquad A_i = A_v \cdot \dfrac{Z_i}{R_L} = -\dfrac{h_{fe}\,(R_C // R_L)}{h_{ie} + R_3} \cdot \dfrac{Z_i}{R_L}$

$A_v = -\dfrac{240}{300K} \cdot \dfrac{R_C R_L}{R_C + R_L} = -800\mu \cdot \dfrac{R_C R_L}{R_C + R_L}$ $\qquad A_i = -80 \cdot \dfrac{R_C}{R_C + R_L}$

$\dfrac{R_C R_L}{R_C + R_L} = 7'5\,K$ $\qquad R_C = 11'97\,K\Omega$

$\dfrac{R_C}{R_C + R_L} = 375\,m$ $\qquad 625m\, R_C = 375m\, R_L$ $\qquad R_L = 1'67\, R_C$

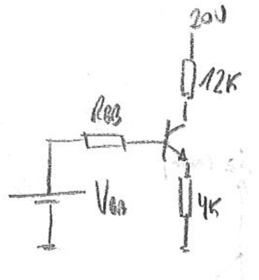
$\boxed{R_C \approx 12\,K\Omega \quad R_L = 20\,K\Omega}$



$R_{BB} = \dfrac{240K \cdot 400K}{240K + 400K} + 298K = 448K$

$V_{BB} = \dfrac{240K}{240K + 400K} \cdot 20 = 7'5\,V$

$h_{FE} = 200 \qquad V_{BEACT} = 0'7V \qquad V_{CESAT} = 0'2V$



$V_{BB} = I_B \cdot R_{BB} + V_{BE} + I_E \cdot 4K$ $\qquad I_{EQ} = (h_{FE} + 1)\, I_{BQ} = 1'091\,mA$ $\qquad I_{BQ} = 5'43\,\mu A > 0 \rightarrow$ ACT ó SAT

$20 = I_C \cdot 12K + V_{CE} + I_E \cdot 4K$ $\qquad I_{CQ} = h_{FE} \cdot I_{BQ} = 1'086\,mA$ $\qquad V_{CEQ} = 2'6\,V > 0'2\,V \rightarrow$ ACTIVA

MARGES DINÀMICS TENSIÓ

$\begin{cases} \Delta V_{CESAT} = V_{CEQ} - V_{CESAT} = 2'6V - 0'5V \\ \Delta V_{CETALL} = V_{CETALL} - V_{CEQ} = V_{CETALL} - 2'6V \end{cases} \rightarrow \boxed{\Delta V_{CESAT} = 2'1V \quad \Delta V_{CETALL} = 8'145\,V}$

$V_{CETALL}\,? \rightarrow$ RCA: $v_{ce} = -i_c\, R_C // R_L$ $\qquad v_{CE} = v_{ce} + V_{CEQ}$ $\qquad v_{CE} = -i_c \cdot 7K5 + 2'6$ $\qquad i_c = i_C' - I_{CQ}$

$i_C' = i_c + I_{CQ}$ $\qquad v_{CE} = 10'745 + i_C' \cdot 7K5$

MES: $\boxed{\Delta V_o = 2'1\,V_{PIC}}$ $\qquad V_{CETALL} = v_{CE}\big|_{i_C' = 0} = 10'745\,V$

$\Delta V_i = \dfrac{\Delta V_o}{A_v} \rightarrow \boxed{\Delta V_i = 350\,mV_{PIC}}$

$I_{CQ} \simeq I_{EQ}$; $16K\Omega$

RCC: $20V = I_{CQ} R_C + V_{CEQ} + I_{EQ} \cdot R_E = V_{CEQ} + I_{CQ} \cdot (R_E + R_C)$

$7KS$

RCA: $v_{ce} = -i_c (R_C // R_L)$; $v_{CE} = v_{ce} + V_{CEQ}$ $v_{CE} = V_{CEQ} + [I_{CQ} - i_C'] \cdot (R_C // R_L)$

$i_C' = i_c + I_{CQ}$

$V_{CETALL} = v_{CE} \Big|_{iC=0} = V_{CEQ} + I_{CQ} \cdot 7K5$

NOUS MARGES DINÀMICS DE TENSIÓ:

$\Delta V_{CESAT} = V_{CEQ} - V_{CESAT} = V_{CEQ} - 0'5V$

$\Delta V_{CETALL} = V_{CETALL} - V_{CEQ} = I_{CQ} \cdot 7K5$

MES ÒPTIMA:

$\Delta V_{CESAT} = \Delta V_{CETALL} \rightarrow V_{CEQ} - 0'5V = I_{CQ} \cdot 7K5$

$$\begin{cases} V_{CEQ} - 0'5V = I_{CQ} \cdot 7K5 \\ 20 = V_{CEQ} + I_{CQ} \cdot 16K \end{cases} \rightarrow I_{CQ} = \frac{V_{CEQ} - 0'5}{7K5} \rightarrow \boxed{I_{CQ} = 0'826 \text{ mA} \quad V_{CEQ} = 6'7V}$$

MES DE SENYAL DE SORTIDA

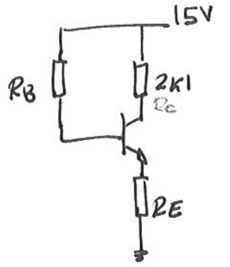
$\Delta V_o = \Delta V_{CESAT} = \Delta V_{CETALL}$ $\boxed{\Delta V_o = 6'2 \text{ V}}$

$V_{BB} = I_{BQ} \cdot R_{BB} + V_{BEQ} + I_{EQ} \cdot R_E$

$I_{BQ} = \frac{I_{CQ}}{h_{FE}} = 4'13 \mu A$ $I_{EQ} = (h_{FE} + 1) I_{BQ} = 0'83 \text{ mA}$

$842'6K = R_{BB} = R_3 + (400K // 240K) = R_3 + 150K$ $\boxed{R_3 = 692'6 \text{ K}\Omega}$

10.

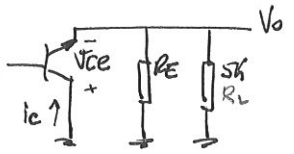


$h_{FE} = 80 \qquad V_{BE\,ACT} = 0'7\,V \qquad V_{CE\,SAT} \approx 0'3\,V$

RCCS: $15V = I_{CQ} \cdot 2K1 + V_{CEQ} + I_{EQ} \cdot R_E = I_{CQ}(R_C + R_E) + V_{CEQ}$

RCCE: $15V = I_{BQ} \cdot R_B + V_{BEQ} + I_{EQ} \cdot R_E = V_{BEQ} + \left(\frac{R_B}{h_{FE}} + R_E\right) I_{CQ}$

$I_{BQ} = \frac{I_{CQ}}{h_{FE}} \qquad I_{EQ} = \frac{h_{FE}+1}{h_{FE}} \cdot I_{CQ} \rightarrow I_{EQ} \approx I_{CQ}$



$V_o = -v_{ce}$

RCA: $v_{ce} = -i_c (R_E // R_L) \qquad v_{CE} = v_{ce} + V_{CEQ} \qquad v_{CE} = V_{CEQ} + [I_{CQ} - i_C] \cdot (R_E // R_L)$

$i_C = i_c + I_{CQ}$

MARGES DINÀMICS DE TENSIÓ:

$\Delta V_{CESAT} = V_{CEQ} - V_{CESAT} = V_{CEQ} - 0'3V$

$\Delta V_{CETALL} = V_{CETALL} - V_{CEQ} = I_{CQ}(R_E // R_L)$

$V_{CETALL} = v_{CE}\Big|_{i_C = 0} = V_{CEQ} + I_{CQ} \cdot (R_E // R_L)$

RB i RE PER TAL DE QUE LA MES SIGUI $V_{o\,màx} = 3'58\,V_{PIC}$

$\Delta V_{CESAT} = \Delta V_{CETALL} = 3'58\,V_{PIC} \longrightarrow V_{CEQ} = \Delta V_{CESAT} + V_{CESAT} = 3'88\,V$

$I_{CQ} = \frac{\Delta V_{CETALL}}{R_E // R_L} = \frac{3'58V}{R_E // R_L}$

SUBSTITUIM EN LA RCCS: $R_E^2 - 8'43K\, R_E + 10'5M = 0 \longrightarrow$ $R_{E1} = 6'91\,K\Omega$, $R_{E2} = 1'519\,K\Omega$

SUSTITUIM EN LA RCCE: $I_{CQ1} = 1'234\,mA$, $I_{CQ2} = 3'073\,mA$ $\longrightarrow$ $R_{B1} = 374'3\,K\Omega$, $R_{B2} = 251\,K\Omega$

CRITERI $R_E \gg \frac{R_B}{h_{FE}+1}$

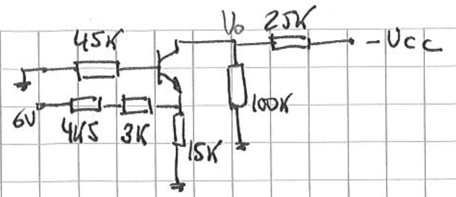
$1'49 \gg 1$

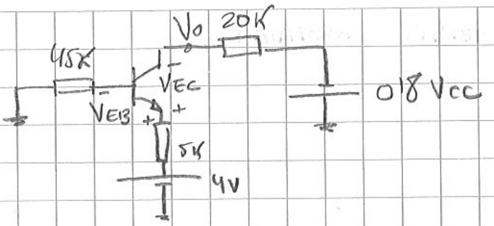
$0'49 \gg 1$

$\longrightarrow$ $R_E = 6'91\,K\Omega$, $R_B = 374'3\,K\Omega$

i A MÉS, ESTÀ EN ACTIVA: $V_{CEQ} = 3'88V > 0'3$

$I_{CQ} = 1'23\,mA > 0$

11. 

→ 

$V_{EC_{SAT}} = 0'3V$

$h_{FE} = 40$

$V'_{CC} = \frac{100K}{100K+25K} \cdot -V_{CC} = -0'8\,V_{CC}$

$R_{CC} = 100K \,//\, 25K = 20K\Omega$

$V_{EE} = \frac{15K}{15K+3K+4K5} \cdot 6V = 4V$ $R_{EE} = 15K \,//\, [4K5+3K] = 5K\Omega$

$4V = I_{EQ} \cdot 5K + V_{EBQ} + I_{BQ} \cdot 45K$ $I_{EQ} = (h_{FE}+1) I_{BQ} = 0'541\,mA$ $I_{BQ} = 13'2\,\mu A > 0$

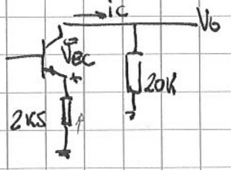
$4V = I_{EQ} \cdot 5K + V_{ECQ} + I_{CQ} \cdot 20K - 0'8\,V_{CC}$ $I_{CQ} = h_{FE} \cdot I_{BQ} = 0'528\,mA$ $\boxed{V_{ECQ} = -9'265 + 0'8\,V_{CC}}$

ACTIVA → $V_{ECQ} > 0'3V$ $-9'265 + 0'8\,V_{CC} > 0'3V$ $\boxed{V_{CC} > 11'95V}$ → ACTIVA

$V_{CC} < 11'95V$ → SAT

RCA: $v_{ec} = -i_c\,(20K + 2K5) = -i_c\,22K5$ $v_{CE} = v_{ce} + V_{CEQ}$

$i_C' = i_c + I_{CQ}$



$v_{CE} = V_{CEQ} + [I_{CQ} - i_C] \cdot 22K5 = -9'265 + 0'8\,V_{CC} + 11'88 - 22K5\,i_C = 2'615 + 0'8\,V_{CC} - 22K5\,i_C$

$V_o = i_c \cdot 20K$

MARGES DINÀMICS DE CORRENT:

$\begin{cases} \Delta i_{C_{SAT}} = I_{C_{SAT}} - I_{CQ} \\ \Delta i_{C_{TALL}} = I_{CQ} - I_{C_{TALL}} \end{cases}$ → $\Delta i_{C_{SAT}} = -425'2 - 35'55\,V_{CC}\ \mu A$; $\Delta i_{C_{TALL}} = 0'528\,mA$

$I_{C_{SAT}} = i_C \Big|_{V_{EC} = V_{EC_{SAT}}} = 102'8\,\mu + 35'55\,\mu\,V_{CC} = 102'8 + 35'55\,V_{CC}\ \mu A$

$I_{C_{TALL}} = 0$

PER OBTENIR MES DE SORTIDA [illegible] DISTORSIÓ (ÒPTIMA):

$20K \cdot \Delta i_{C_{SAT}} = 20K \cdot \Delta i_{C_{TALL}}$

$-425'2 - 35'55\,V_{CC} = 0'528$ → $\boxed{V_{CC} = 26'81V}$

* $I_{BQ} = 13'2\,\mu A$ $I_{EQ} = 0'541\,mA$ $I_{CQ} = 0'528\,mA$ $V_{ECQ} = 12'18V$

COMPONENT TOTAL DE TENSIÓ SORTIDA:

- $v_O = V_O + v_o = -10'54 + 20K \cdot i_c$

$v_o = i_c \cdot 20K$ on $i_c = I_{C_{MAX}} \cdot \sin(\omega t)$

$V_O = R_{CC} I_{CQ} - 0'8 V_{CC} = -10'54\,V$

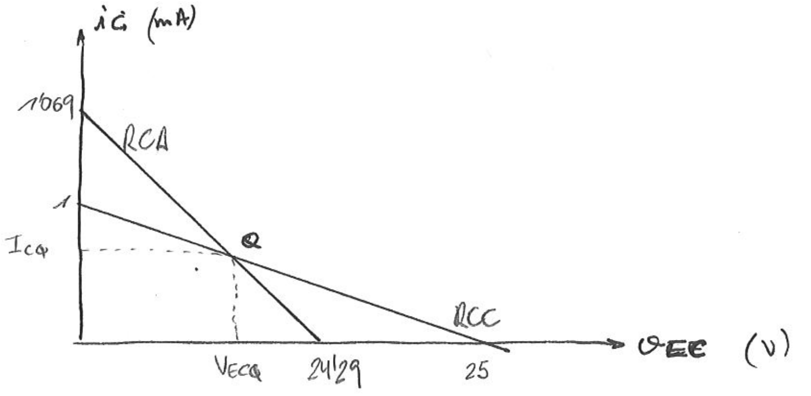
VALOR MITJÀ:

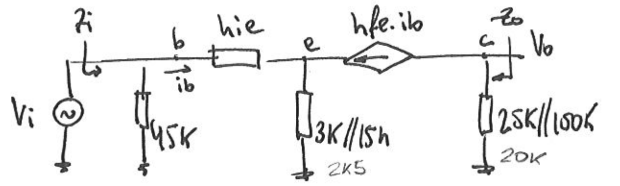
$$v_{O_{1/2}} = \frac{1}{T}\int_0^T v_O\,dt = \frac{1}{T}\left[-10'54\,T + 20K\right]\cdot\int_0^T i_c\,dt$$

$$\boxed{v_{O_{1/2}} = -10'54\,V}$$

RCC: $I_{CQ} = \dfrac{25'5 - V_{ECQ}}{25K} = 1 - 0'04\,V_{ECQ}$ (mA)

RCA: $i_C = \dfrac{24 - v_{EC}}{22K5} = 1'069 - 0'044\,v_{EC}$ (mA)





$h_{ie} = 700\,\Omega$ $h_{fe} = 50$

$V_o = -h_{fe} \cdot i_b \cdot 20K$

$V_i = h_{ie} \cdot i_b + (h_{fe}+1) \cdot i_b \cdot 2K5$

- $A_V = \dfrac{V_o}{V_i} = \dfrac{-h_{fe}\cdot 20K}{h_{ie} + (h_{fe}+1)\cdot 2K5} = \underline{-7'8}$

- $Z_i = 45K \,//\, Z_i' = \underline{33K3\,\Omega}$

- $\underline{Z_o = 20K\Omega}$

$Z_i' = \dfrac{V_i}{i_b} = h_{ie} + (h_{fe}+1)\cdot 2K5 = 128K2$

Fecha:

Asunto: Página:

MÀXIMS VALORS DE V_o i V_i. $V_{CC} = 21'5V$

$\Delta V_o = 20K \cdot \Delta i_C$

MARGES DINÀMICS CORRENT:

$\Delta i_{CSAT} = i_{CSAT} - I_{CQ} = 0'867m - 0'528m = \underline{0'339\ mA}$

$\Delta i_{CTALL} = I_{CQ} - \underset{0}{i_{CTALL}} = I_{CQ} = \underline{0'528\ mA}$

$i_{CSAT} : i_C \Big|_{V_{CE} = V_{CE_{SAT}}} = 0'867\ mA$

$\Delta i_{CSAT} < \Delta i_{CTALL} \longrightarrow \Delta V_o = 20K \cdot \Delta i_{CSAT} = \boxed{6'78\ V}$

$\Delta V_i = \dfrac{\Delta V_o}{A_V} = \dfrac{6'78}{7'8} = \boxed{0'869\ mV\ pic}$